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SYNTHESIS OF A MULTIFUNCTIONAL TACTICAL LANDING SYSTEM

G. B. LITCHFORD

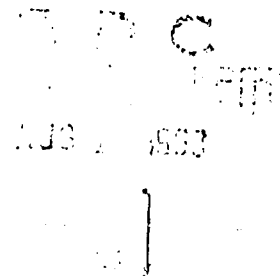
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TECHNICAL REPORT AFFDL-TR-67-188

January 1968

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Air Force Flight Dynamics Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio



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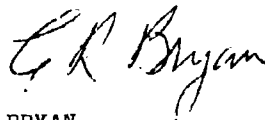
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FOREWORD

This report was prepared by George B. Litchford, consultant to the University of Dayton Research Institute, under USAF contract AF 33(615)-3199; project No. 682C, for the AF Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Mr. Terry J. Emerson was Program Manager for the Systems Integration & Flight Experimentation Branch, Flight Control Division. Valuable suggestions were made by George Yingling, Chief of the Systems Integration and Flight Experimentation Branch and Mr. S. Knemeyer, Consultant to the Chief of the Flight Control Division.

Engineering work on this project was conducted during the latter part of 1966 and completed in January 1967. After review and discussion, this report was submitted for publication in October 1967.

This technical report has been reviewed and is approved.



C. R. BRYAN
Actg Chief, Flight Control Division
AF Flight Dynamics Laboratory

ABSTRACT

There is no denying that an urgent need exists to establish a tactical means for all-weather landing. Although techniques are now being tested, under civil auspices, for low visibility landing conditions of "see to land" from a 150-foot height with 1200 to 1800 feet of runway visual range, they are not applicable to most tactical situations. Furthermore, it is unlikely that by a fortuitous set of circumstances a so-called "break-through" in this technically sophisticated area will occur.

The proliferation, in recent years, of industry-developed equipment intended for tactical landing is a partial indication of the problem. It is unlikely that any of these systems as they are presently configured will meet the real needs of a tactical landing system. To acquire an inadequate landing system for tactical deployment can not only produce lethal results, but can also forestall the much-needed development for several more years. It is unfortunate that the characteristics for such a landing system have not been previously clearly established. This report is an attempt to outline the methodology and means required to establish these characteristics.

Low visibility landing, and particularly the restraints placed on a tactically acceptable system, are probably the most demanding of any of the current technological problems facing the Air Force. As experience indicates, there are no short-cuts to success in this field. First, a logical step-by-step process for synthesizing a tactical landing system program is essential. With adequate interest, personnel, facilities, and funding, a suitable solution can be developed.

The magnitude of the effort, and the often unsuspected inter-governmental impact of tactically justified development of navigation facilities are outlined. Those not familiar with these somewhat non-technical aspects of the problem should carefully consider their significance.

Since the Civil-ICAO systems are also used by parts of the Air Force (at permanent bases) and are not likely to be replaced for some years, the inference is that the Air Force will actually be burdened with two landing systems. Only by a concerted effort can this be limited so that a third or fourth system does not evolve and stalemate what could be a future Air Force standard. Thus, in the determination of the program, the effort must be sufficiently organized and visionary to avoid these pitfalls. Fortunately, landing technology has advanced to where this is possible. By their very nature, landing systems must be as common among the Air Force Commands as the English language itself.

The challenge is to establish a program that will lead to the adoption of an electronic "Signals-in-Space" standard. This,

in turn, will permit various forms of the basic system to evolve while maintaining airborne commonality with as many ground services as possible.

Just as an aeronautical engineer designs a successful aircraft by use of recognized ground rules or by consideration of wings, engines, mission, etc., so must the designer of tactical landing systems learn to consider radio frequencies, beams, modulation techniques, etc.

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SECTION I

THE PHILOSOPHY OF SYSTEM PLANNING

The likelihood that the Air Force (or other services) will arrive at a satisfactory Tactical Landing System that can be established with a "Signals-in-Space" standard by random developments is very low. About three dozen landing system developments, many of them with possible tactical applications, have been undertaken over the past several years. Since World War II, no new system has been worthy of quantity production and utilization. As noted in references 61 and 62, the need for commonality among the military services and particularly within a given service is essential. Several incompatible landing systems simply cannot be tolerated.

Each past landing system development, because it has not adhered to a set of common standards, operates at a different frequency, with different beam configurations, beam encoding methods, etc.; thus, those responsible for assuring some integration of military electronics among the Services, cannot find a clear path for a decision. The inconsistency of claims, numbers of techniques, lack of suitable test data, etc., has simply stalemated the decision-making process. Perhaps no decision has been the best decision. Although a "no-decision" is often regarded as poor in the military sense, the lethal nature of a poorly conceived and used landing system is undeniable. Already, 50 percent of aviation fatalities are related to landing accidents. The cost to achieve the Air Force Tactical Landing System goals will be high; therefore, the pressure to use a short-cut solution to such a system will be great.

The problem is a complex one: to establish a "Signals-in-Space" standard that will meet the diverse needs and at the same time retain simplicity and require minimum air and ground equipments. The best of guidance is needed for its solution. As reference 77 notes, "expediency is false economy; reduces engineering to tinkering; poisons initiative, etc.." and "real economy in engineering is the best use of every available aid in arriving at an understanding of the problem and an expeditious solution." It is most difficult and in fact requires very hard work to find the "easy way." Finding the solution to the class of problems makes the solution of a specific problem almost routine.

Reference 76 notes that since the complex solution is usually taken to save time, yet costs enormous amounts more, "decision makers are coming to believe that the best way to avoid development costs and problems is to skip the development phase altogether and begin by designing the production model." He further states that an argument for reducing complexity is "The operators of our fighting ships and aircraft of today, and more so in the future, will require

long years of training and experience to cope with the complexity built into the devices." Complexity is characterized as a "short cut in time to the accomplishment of a goal, at a terrific price when insufficient knowledge exists." "As a sufficiently wealthy nation, we have come to accept the price for the sake of getting something we want very badly as fast as possible."

As one looks broadly at the current Air Force and other Service positions with regard to instrument landing and particularly tactical instrument landing, it is evident that a well-organized, funded and managed development program must be first formulated. Otherwise, a continuation of the proliferation of dozens of potential landing systems will persist. The latter is tragic, since the industry engineering effort being spent is often wasted and the funding of random programs is a major fraction of what a balanced organized program would cost. Therefore, a completely defined project approach is the only expeditious route to success.

If one were considering inertial navigation equipments, for example, where several contenders exist with different technology, accuracy, etc., one is not forced into the same kind of a decision. Being self-contained and non-cooperative even a half-dozen system developments (for various missions, prices, and accuracies) might be good planning. Where a cooperative system with high user risk and an obvious common solution is needed, the simple approach typified by the inertial programs cannot be taken. The tactical landing system problem falls into the latter category.

Although not generally recognized, low visibility landing is the most demanding of all forms of navigation. Not only is the required precision high, but the necessary aircraft instrumentation to fly safely without seeing the ground obstacles before visual contact is made at low altitudes, requires the epitome of engineering. Great ingenuity is required to provide the ability to have a "Signals-in-Space" standard that satisfies the bare base for full portability and the main base for large aircraft. There is a reasonable degree of assurance that the technology of the 1968 era can achieve this, and that this major bottleneck to a complete all-weather capability for the Air Force is within view.

The price tag should be mentioned. In rough terms it is likely to be equivalent to the development of a new aircraft. The Air Force management structures in cooperation with industry have achieved many successful airborne weapons systems. The extent of the effort is likely to be of this magnitude. If this is not recognized another decade of frustration and incompatibility will prevail without arriving at the essential ingredients needed for successful all-weather use of military aircraft.

Often, planners look to a fully "self-contained" solution, so that the problem seems easier and one does not have to worry about such things as "Signals-in-Space," inter-service compatibility, and commonality. Ground units are not needed. At this stage of development, this is only a dream and should be recognized as such. No self-contained guidance system today can come anywhere near the accuracy, flexibility, and dependability, essential for low-visibility landing. The principles of Doppler, inertial, celestial, etc., may be fine for long-range navigation wherein a mile (6,000 feet) or more of positioning error is acceptable. IFR landing accuracies are measured in feet--about three orders of magnitude more precise than self-contained aids. Admittedly, extremely complex units for special purposes have been developed that can do better on a fully self-contained basis, but they are not applicable to the large numbers of aircraft that are in serious need of a tactical landing capability.

It will require recognition that full emphasis must now be placed on the cooperative concepts of (air and ground) units. For example, a small ground unit with a microwave localizer can provide far superior accuracy (alignment, precise location of poorly mapped forward strips, etc.) than any self-contained aid; furthermore, use of such a unit would considerably reduce the cost for the airborne units. The basic argument, of course, against the ground cooperative unit (no matter how simple and light) is the need for a person or persons to install it. An examination of Air Force doctrine, particularly with regard to safety and accident investigation, indicates that personal ground inspection and preparation is made for a new landing site. No matter how trivial it is, whether it be a "bare base," "hasty base," or "rapid base," it is studied.

Thus, the effort to establish even a clearing for a helicopter in a brush warfare exercise depends on the ground inspection and some simple aids such as communications. Obstacles, night-time operation, unknown winds, overshoot areas, climbout rates, etc., all must be established. In doing this, the additional small units needed for a cooperative landing system can become a part of the SOP for this determination.

In fact, it can be argued that the addition of such guidance units might well qualify a greater number of sites. The tactical advantages of a wider site selection are obvious.

1. LANDING SITE COORDINATES

For example, a site can be used with a cooperative ground unit, even though the site has not been fully surveyed or located on maps with respect to other known locations. Thus, an essential requirement of any fully self-contained system (knowledge

of precise coordinates) is avoided. Many parts of the world, where tactical landing may be essential, are not surveyed in the interior so that destination coordinates are lacking. A small localizer at the intended site solves many of these problems. The site may never be precisely surveyed, since the battle lines may have moved before such measurements are completed.

Thus, in recapping the philosophical observations, one concludes that, though initially a difficult undertaking, the cooperative system with a "Signals-in-Space" standard is essential. Distractions of potential, fully self-contained landing aids are illusionary for the present, and for operational reasons may possibly never be realized in many remote parts of the world.

The section of this report relating to the "Synthesis of a Multi-function Tactical Landing System" is based on these premises. Assistance in locating the Approach Signal Coverage, utilizing some of the existing airborne electronics, is broadly assessed. It is somewhat distressing that although dozens of references relating to the capability of cooperative systems exist, little similar data exists for the instrument approach or landing use of airborne radar, inertial, celestial, or Doppler.

Some field data on an organized basis should be gathered and published so that the record is complete on this subject. The estimates possible from the very limited data on these subjects leads one to believe that these aids are far from suitable for actual low-visibility guidance. They may be used, however, in special cases for locating the wide signal coverage of a portable localizer.

2. SUMMARY

It is unlikely that the requirements for a tactical landing system will be met by random selection of the many varied systems proffered by industry. The developers do not have the insight and they do not have the large resources needed to go through the complex development of what will eventually be a simple tactical landing system. Engineering for simplicity without losing utility and safety is the most difficult engineering. Industry cannot afford to provide this function without guidelines, which are rightly the responsibility of the government. The Air Force will be the customer, and is the only one that can define and prepare standards for the solution of its own needs in the tactical landing area. With such leadership, the numerous industry interests, if then funneled toward a common objective, can be most beneficial. Their investments can be more rewarding: their services will see useful results and a DOD common objective is realizable.

The Air Force has the most at stake in the decision because of its large numbers of aircraft, personnel, and mostly because of the great diversity of aircraft types and missions. The Army is typified by the helicopter tactical mission; the Navy by the aircraft carrier mission. The Air Force is more diversified. Airline type operation with the MAC, which is staffed with over 100,000 personnel, is but one form of activity. The Air Force uses helicopters, the fast landing jet fighter with its GPIP problems, the SAC heavy bombers, etc. An adequate Air Force solution to tactical landing is likely to meet most other service requirements.

Thus, it is important that the Air Force take the view that it develop within its own ranks a common "Signals-in-Space" concept for its own purposes. Having done this, the Tri-Service coordination is well advanced, since all but a few special missions and aircraft types are included. The Navy is already pursuing its carrier landing problems through a special project office (ACLS Office--All Weather Carrier Landing System). The Army is intensifying its effort to establish an IFR helicopter landing and guidance capability. From the magnitude of the problem it would appear that each Service can pursue its objectives without duplication of other activities once an agreement on the "Signals-in-Space" Standard is reached. If anything, the gross effort is currently inadequate.

a. Landing System Developments

Many of the landing system developments since World War II have had definite tactical applications. Although not complete, it is very informative to review some of these developments, to note the variety and particularly the lack of any common standards (Signals-in-Space). It would seem that each program hoped somehow to become dominant and then to somehow encompass the other missions and objectives. That this has not happened is obvious, probably because of the extreme technological demands placed on a tactical landing system that is common to many missions. It must encompass many diverse types of aircraft, be suitable for rapid installation and commissioning in a wide variety of sites all around the world, and have some close relationship with the International Civil Requirements where such overlap exists.

TABLE I

LANDING SYSTEM DEVELOPMENTS SINCE WORLD WAR II

<u>Nature of Landing System</u>	<u>Radio Frequency</u>	<u>Company or Agency</u>
1. VHF overlapped beams (glide path)	400 Mc	MIT-CAA
2. Overlapped microwave beams (Loc. & GP)	2600 Mc	Sperry-AF
3. Military-ICAO-ILS (MRN-7, MRN-8)	110-330 Mc	ITT-AF
4. Locked radar data link (GSN-5)	36 kMc	Bell-AF
5. Locked radar data link (SPN-10)	36 kMc	Bell-Navy
6. Selectable glide angle microwave	5 kMc	Sperry-AF
7. Scanning beam vertical guidance	10 kMc	Gilfillan-AF
8. Scanning beam conceptual study	open	AF with Sperry, Hughes, Gilfillan, AIL
9. Scanning beam with DME (REGAL) (vertical only)	10 kMc	FAA-Gilfillan
10. VORLOC (small VHF unit)	VHF	Cubic
11. VHF approach and letdown	UHF	Sperry (Phoenix) (Army-AF)
12. Radio Altimeter Concepts		
a. Autonetics (APN 114)	Pulses,	AF
b. FAA-CAT II	FM, etc.	FAA
c. Minneapolis Honeywell	of about	BLEU
d. Litton	three	ATA
e. ITT/Standard Cables	different	IATA
f. Sperry	microwave	ICAO
g. Lear	frequencies	NAVY
h. Collins		
i. Etc. (about 5 smaller projects)		
13. Flarescan-ILS (flare guidance)	15 kMc	AIL-French FAA/AF/NASA
14. AILS (integrated beam guidance and GCA)	15 kMc	AIL-FAA
15. SPN-42 Modernized, SPN-10 with beacon micromin, etc.	36 kMc	Bell-Navy
16. SPN-41 Scanning beam carrier approach (loc. and GP) microwave ILS	15 kMc	AIL-Navy
17. TALAR (single site, light weight, conical scan GP and Loc.)	15 kMc	GPL with AF, Navy, etc.

TABLE I (cont'd)

18. TALAR II (improvements)	15 kMc	GPL-Navy
19. STATE, single site microwave ILS time shared lobes, single rec.	5 kMc	MH-AF
20. RAILS Airborne directive antenna aimed at ground beacon	X-band	Bell-Army
21. SAILS improved system	?	Bell-AF
22. Magnetic cables, approach, flare and roll-out guidance	1-2 kc	Murphy radio RAF-BLEU FAA
23. Optical Glide Slopes		
a. Fresnel lens (carrier stabilized)	directive red, green and white light	Navy Burroughs
b. Mirror System	similar	NAA-Navy
c. "Rainbow" glide slope	Path according to color	Lockheed Navy FAA-UK
d. VASI	10 kMc	Gilfillan Bendix ITT
24. GCA (about 5 models) radar talk-down system scanning microwave beams		US/Europe/ICAO ITT Gilfillan Lorenz
25. PAR Civil version of GCA with landing guidance (horizontal and vertical scanning beams)	10 kMc	Gilfillan-Army LFE-Army-Marine Gilfillan Tri-Service Navy
26. Quad radar--light weight GCA	10 kMc	
27. SPAR--light weight GCA	10 kMc	
28. TPN-8 Light weight GCA	10 kMc	
29. SPN-35 Light weight GCA	10 kMc	
30. Zero-zero- pictorial landing beacons outlining runway	UHF microwave	NASA-Cubic Bendix
31. Microvision beacons outlining runway view with airborne radar display	X-band	Sperry FAA-AF
32. Fully self-contained landing guidance proposed for C-5A and similar missions Airborne-radar-inertial, etc.	various	Tri-Service C-5A -AFASS etc.
33. Interferometer-terrain radar and surface reflectors or beacons	various	Navy-Norden AGA typical
34. ATLAS (light weight REGAL type)	?	Gilfillan
35. Army MK II (study)	microwave	Cooke-Army
36. Future-Army (study)	radio, IR microwave, others	RCA-Army

TABLE I (cont'd)

37. CSF Landing System; directive glide path split localizer DME	L-band	CSF-CEV: French military
38. TAILS (light-weight landing system study)	microwave	Tridea (McDonnell) Marines- study stage
39. Time/Frequency (use of air and ground time standards)	microwave	TRG Sierra McDonnell National Co.
40. TACAN-ILS	L-band compatible with TACAN modulation	ITT-AF
41. DME let-down computers	DME and altimeter for com- puted descent to specific point	Bendix-AF FAA-Navy- Johnsville Air Force others
42. Adcole Helicopter System	K _u band with VHF conver- sion	FAA-Adcole
43. FAA-UHF Microwave Conversion	S- or C- band converter to ILS frequencies	FAA proposed

It should be noted that this list is not complete. However, it exemplifies the technical confusion and proliferation of landing system developments. As will be noted, there are at least five different, incompatible bands of radio frequencies. Many conceptually different techniques exist. Even the radio signals using the same band have no commonality of modulation signals: there being pulse, tones, FM, FSK, T/F, phase and amplitude comparison, pulse spacing, pulse length, digital coding, etc.

As a matter of fact, it is doubtful whether more than two of the many systems listed have any commonality in the sense that either the ground or air equipments are mutually inclusive. The national cost to date for these developments is enormous. On the positive side, however, is the fact that in the last twenty years the ILS and GCA of World War II have undergone several refinements. There have been at least twenty programs for ILS improvements (null reference, directive dipoles, flush antennas, directive waveguides, M array, capture arrays, V-rings, waveguide localizers, MRN-7 and MRN-8, CAT. III, and solid state). These have primarily taken forms suitable to ICAO-FAA for lack of definitive military guide lines. Certainly, the concept of mobility, portability, or even rapid airlift have been completely lost in the developments of standard ILS.

The current ILS is much further from a portable system than it was in 1942 (SCS-51). Admittedly, the current ILS systems work much better and do not have as serious deficiencies as the SCS-51, such as course bends, false courses, weak signals, etc. Fortunately, there is a lesson to be learned here. What has really happened is that beam directivity of one form or another has been added in each improvement of the ILS to obtain improved quality of courses and monitoring stability. These improvements resulted in large increases in the size of antennas (now 100 feet high for glide slopes and 100 feet wide for localizers), each weighing several tons for their support and radiating elements.

This same beam configuration at microwave frequencies can be achieved with 1/50 to 1/10 of the same dimensions. Directivity and beam radiation control are undoubtedly as essential (if not more so) to a tactical

landing system as to a civil system, because the wide obstacle clearance criteria for qualifying civil fields cannot be assured in rapidly prepared landing sites in the military zone. This is true of the obstacle (vertical) and horizontal (approach and off centerline) criteria of a tactical site. The Army criteria for a tactical heliport state a 1/10 obstacle line on approach and a 1/2 obstacle line on the side. These obstacle lines of 6 degrees and 45 degrees infer that reflecting objects can occupy the space beneath these areas. These objects can reradiate or become landing hazards, two serious tactical landing considerations.

It can be argued perhaps that the wide diversity of landing system developments should continue as in the ancient case of alchemy, since someone might discover the ideal landing system and all the problems of low visibility, tactical solutions, and other related matters would be resolved. Probably no other aspect of the fields of electronics and aircraft area is more replete with failures. During the last three decades, over fifty recognized attempts have failed. The above list speaks for itself. Some of the reasons for the failure to achieve an acceptable tactical landing system are:

1. Lack of understanding of the problem.
2. Lack of any coordinated or sustained governmental support for tactical systems.
3. No center for such developments exists in the Air Force, since the termination of the All Weather Flying Division. The Navy now has one.
4. Many self-styled experts with limited understanding of the total problem (human, instrument, radio, aerodynamics, flight control, visual, landing criteria, etc.) have invented solutions to limited portions of the problem that they have encountered.
5. No comprehensive analyses of all aspects of the total problem and their many inter-relationships exist.

6. No realistic means is now available for fully testing the validity in the appropriate environments, with quantitative published results of many of the past developments. BLEU is a small-scale example of what is meant here. The total environment is: visual aids, radio guidance, aircraft instruments, pilot factors, aircraft controls and aerodynamics, actual current operational aircraft available for testing (not slow piston aircraft for testing a jet fighter system), etc.

Broadly stated, perhaps the most important reason is the lack of an organized attack on all aspects of the problem in a logical engineering manner. The price for not having a landing system suitable for tactical and other military applications is already costly in terms of accidents. The new airlift concepts costing billions will not be realized to their true potential unless this major step is taken. The reduction in landing accidents alone could justify this effort (say about 25 million/year for five years). The Navy has funded about 250 millions for (references 86 and 98) the overall carrier landing program up to the present.

The recognition that the solution to the Air Force landing problems is the equivalent of a major weapon system development with appropriate funding, management, and top echelon recognition is essential to their rapid resolution. Once established, the system must also be able to cope with continuing landing problems brought on by the rapid advances in aircraft, such as V/STOL, etc. The likelihood that a continuation of random technical efforts, each with insufficient funding, without any standards of "Signals-in-Space," will create a satisfactory solution is only wishful thinking in today's technology. A well-funded, well-engineered "total" systems approach can get results.

b. What Can Be Gained From the Past

As stated previously, all the effort is not lost simply because the desired tactical system has not evolved. The past efforts, though ineffective, should be culled over by a qualified group to extract the gains that have been made. Even the cause of failure is important to future success. The large numbers of companies, agencies, and countries involved have contributed pieces and parts, many of them without thought to a gross, integrated approach, but with several of them providing something of value. Even reports on projects costing large sums of money are hard to locate. Some of the areas worth looking into from past experience are:

1. Propagation of radio signals for landing guidance (reflections, weather absorption, stability, interference, etc.).
2. Accuracy of various techniques for beam formation, beam modulation, and processing of data in the aircraft for control purposes.
3. Flight test results. Quantitative measurements of flight path, course quality (beam perturbations), signal levels, adverse affect (prop or rotor modulation), and variation in vertical and horizontal course direction and sensitivity. Pilot opinion is too varied, even among professionals, for the engineer to make progress without these measurements. Do qualified test results exist that will aid in establishing a "Signals-in-Space" standard?
4. Pilot response to combinations of displays, instruments, control parameters and guidance signals of various types.

From such a re-examination perhaps many paths can be avoided that would lead to future failure. Today, only through personal contact does this integrated knowledge exist. Even there it exists as "islands of knowledge"--some relating only to the airlines, some to the carrier landings, some with the many forms of ICAO, ILS, and some in pilot instrumentation. The objective would be to bring the millions spent in the past into focus for evaluation.

A re-examination of past efforts may or may not be of worth when engineering guidance is needed. However, it will probably be essential politically since so many individuals have been involved in parts of these programs and the avoidance of duplication is important. The integrated documentation should serve for years in the future since no text books exist, no universities teach the subject, and many of the older developers have moved on to other better recognized fields. It will be necessary to create a "science" of the landing guidance field. It touches every aircraft flying. To do this, records of past experience must be kept and means of passing on what valuable information and data exist to those that will enter the field. Perhaps a university group could undertake this, not delaying or interfering with many possible concurrent efforts.

SECTION II

LANDING PROFILE MEASUREMENTS AND THEIR RELATIONSHIP TO TACTICAL (LANDING SYSTEM) GUIDANCE

Little flight-validated information in a quantitative form is available to the guidance system designer relating to the actual flight path followed by modern tactical aircraft from below 300 feet to touchdown. References 10, 11, 17, 21, 34, 35, 81, 92, 93, 100, and 106 have some information on this significant system parameter, but much of it is conflicting, and more detailed information is needed. References 23 and 36 are the only significant engineering reports on this matter. One is an FAA (photo-theodolite) measurement of VFR landing parameters of current jet transports operated by the airlines in civil fields. The other is a WADC report of a photo-grid measurement of current Century-series Air Force fighters.

Both reports throw considerable doubt on current standards used by the FAA and the Air Force. The discrepancies include aiming points, threshold heights, touchdown distances, threshold sink rates, and other landing parameters. Furthermore, little or no published data on IFR operations exists. However, the FAA is now sponsoring an IFR landing measurements project (for Civil jets at large Civil fields) that will provide additional information toward the end of 1967. A similar IFR measurements project is sorely needed in the Air Force because of the (1) widely divergent flight paths of the variety of tactical aircraft it uses and (2) widely divergent environments each of these aircraft may encounter in tactical deployment.

Figure 1 illustrates this point. A few aircraft types with differing landing profiles are plotted in a manner that causes all touchdowns to coincide. With this common touchdown point (most significant to a landing system designer), it is evident that trajectories emanate from it into the approach zone at angles from around 1/2 degrees to as high as 10 degrees. The higher approach angles suggest a possible future V-STOL capable of IFR approaches up to around 15 or 20 degrees. The lower approach angles suggest a very high performance vehicle (advanced SST or equivalent--or an enormous, oversized jet airlift vehicle).

In the high-angle cases, the heavy, turbine-powered helicopters of the V-107 are shown (based, admittedly, on limited data) that might represent the CH-47, CH-54, HH-30, CH-46 and others currently operational. With the enormous G and D in the V-STOL field, much aimed at almost vertical descent, a landing system for tactical usage (10 to 15 year life span)

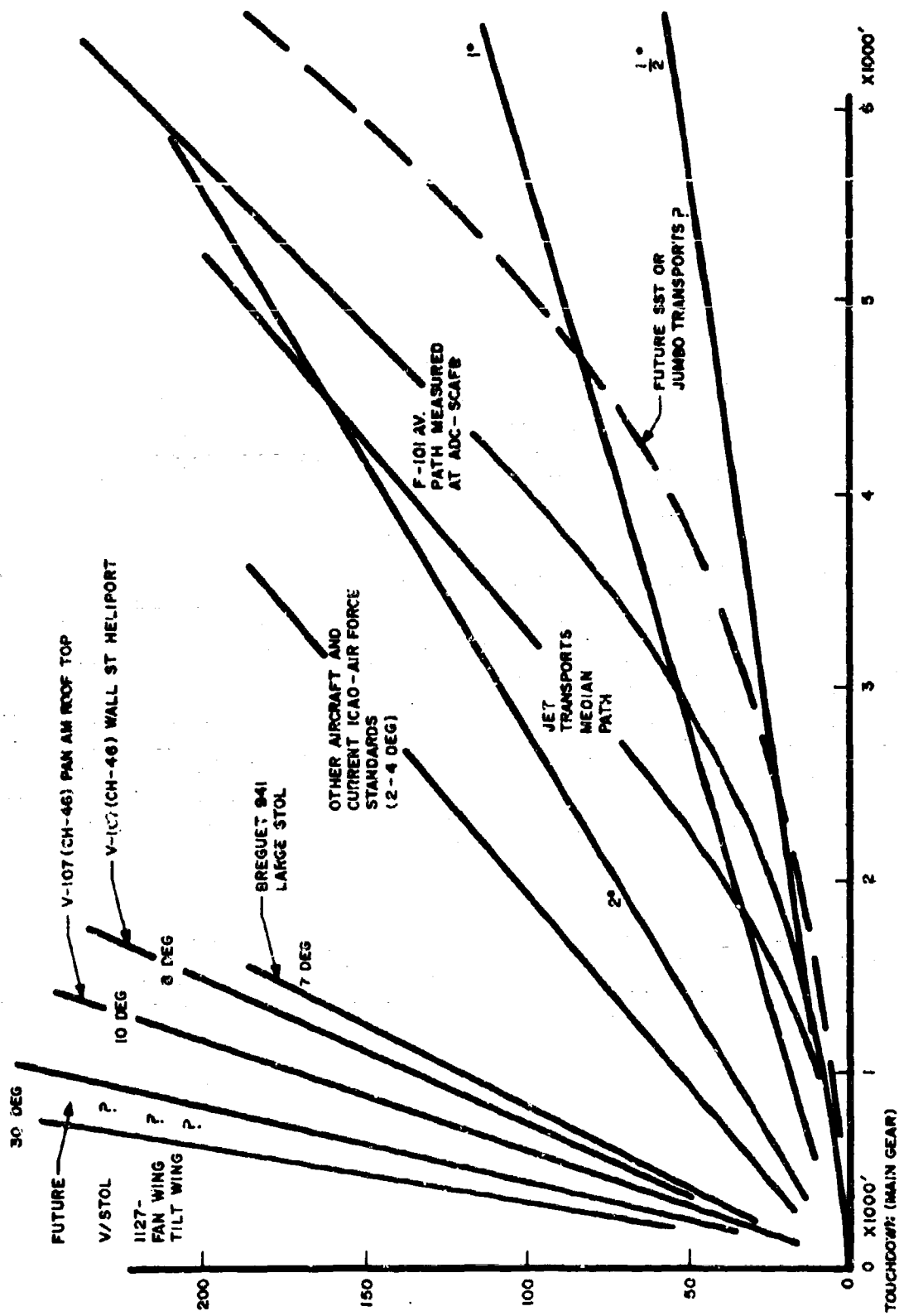


FIGURE 1. TYPICAL LANDING PROFILES

should consider angles up to perhaps 30 degrees. Beyond these angles (considered high by some experts) wind shear, control problems, aerodynamics, safety, piloting problems, vehicle response, etc., become overwhelming operational problems. This is particularly true as J. Reeder (NASA) recently noted when he pointed out the following IFR-V-STOL landing problems to an AIAA gathering.

1. Specific path to a specific point is much more difficult.
2. Most designers think only of free space instrument flight with no specific path or point of termination.
3. Few pilots have tried it.
4. A specific path flown to a specific spot at low speed, and steep angles encounters problems such as:
 - a. High angular rates of deviation from path due to low speed.
 - b. Vanishing acceleration cues for the pilot.
 - c. Pronounced wind gradient and shear effects on glide path and track.
 - d. Backside of the power or thrust curve.
 - e. Small inherent stabilizing moments and damping with respect to all axes.

It is apparent that a whole new area of tactical landing guidance exists if V-STOL are to be utilized in IFR. Returning to the other extreme, little is known about some of the advanced large vehicles with supersonic (or even subsonic) capability. Because of their very size and gross landing weights (inertia), maneuvering (flexibility) below a 100-foot landing height (to touchdown) will be much less than is possible even with the current jet transports. The large sizes result in poor handling properties, poor pilot judgment, poor and misleading visual cues (pilot's eyes 200 feet ahead and 70 feet above bottom side of landing gear), etc. Lacking anything better it is suggested that the F-101 data that is representative of many current jet fighters serve as an indication of trends toward flat, minimum maneuvering, IFR landing flight paths until suitable additional data is accumulated.

A likely addition in future years to the tactical aircraft inventory is the medium and large STOL aircraft. As

the need to cope with Southeast Asia (SEA) type operations increases, the STOL has the attractive features of large payloads, low cost per ton per mile, and a basically simpler concept than either the helicopter or V-STOL (conversions). It will land in short strips from rather steep approach angles. It is shown on the illustration as the Breguet 941 with a path angle of around 6-8 degrees.

1. ROLL-OUT GUIDANCE

Tactically, with a Runway Visual Range (RVR) of 1200 feet or more, it is desired that no electronics will be needed for V-STOL roll-out. The helicopter rolls to a stop after a flare in such a short distance that often a figure of two to three times the rotor blade diameters is considered an adequate landing dimension. The STOL falls in the 400 to 1000 foot class, while the prop jet is in the 2000 to 3000 foot category. Pure jets range from 5000 to 6000 feet for tactical field lengths.

In cases of longer roll-outs it is evident that a localizer signal at the roll-out end of the landing strip is essential to assure centerline alignment and to indicate crab angle for low visibility and nighttime (minimum lights) operations. From the landing system design viewpoint, this requires adequate beam accuracy, stability, and freedom from beam bends to meet this requirement. This is evident since guidance sources may be located up to 5000 to 8000 feet from the threshold of the runway (at roll-out end). Proposals to locate the localizer signal source at the approach end of the runway have serious deficiencies because of the extreme angular convergence, blocking of the radiated signal by the airframe, and the lack of guidance during the flare, touchdown and roll-out. The latter may be extremely important for anything approaching a 100% capability with tactical jet fighters or airlift aircraft.

The roll-out characteristics of an aircraft can have a far-reaching effect on the design parameters of a tactical landing system. As noted elsewhere, it is not considered likely that the 3000 feet of approach, runway centerline, and parameter lights will be installed at forward bases. This places demands on radio guidance that are much more stringent than Civil examples. This is one basic difference between a Civil or permanent Military field and can be coped with if adequately considered in the synthesis stages of the development of a tactical landing system.

A minimum, visual guidance light, similar to the Navy portable (trailer) optical glide path or "meat ball" is proposed to give some assurance in low visibility. The "see-to-land"

* A pilot visual decision height of 100 feet with a runway visual range of 1/4 mile or 1200 feet.

concept is basic to CAT I, II, IIIA, and IIIB landing criteria. Thus, a highly portable visual aid such as a modified meat ball could meet this requirement. Since the jet flare is not a straight path, it is possible that a meat ball placed so as to check the pilot's path in the flare region (around 1 degree) might be more beneficial because it would aid in establishing the flare touchdown point (the current meat ball is only for approach aim points). Perhaps two optical paths for approach aiming and flare aiming are needed.

Lighting for landing guidance is really another important subject that needs study in the tactical landing field and should marry with and complement the tactical radio guidance system. We will not pursue the lighting field any further here, but suggest an independent study to assure that the tactical aspects of a "see-to-land" from an IFR approach are not overlooked.

2. DETAILS OF FLIGHT PATHS

Some camera data was taken recently at an operational ADC squadron at Suffolk County Airport (NY) with F-101 aircraft. The results are illustrated in Figure 2 and Table II, since it is believed to be completely unbiased data (pilots unaware), and it is at variance with current Air Force Standards, as documented in the recent "TERPS" (references 22 and 37). The present standards for GPIP and flight paths do not recognize the long, flat, flare profile of these and similar aircraft. Many tactical aircraft are similar to the F-101.

The four landings to be described are typical of a larger number that were recorded and reviewed for general characteristics, but not quantitatively measured.

The pilots of F-101 aircraft tend to fly the VFR approach (to land) at a flight path angle in excess of 3.0° toward a point about 1000 feet in front of the threshold. The 4000 feet of forward flight from a height of 100 feet above touchdown used by the Air Safety staff (references 34 and 35) in the Air Force was reproduced. What is new are some rather significant dimensions of the flare trajectory that suggest major changes in ILS reference points and GCA-GPIP since the pilot, upon breaking out of a ceiling of even 300 feet, would have some rather excessive sink rates to contend with if he is to land where he normally does in VFR.

The maximum deviation below the ILS (or GCA) glide slope is 90 feet. This requires the pilot to abandon the ILS and fly below it from a height of no less than 300-400 feet,

if excessive sink rates that may cause striking short of the runway threshold are to be avoided. Threshold conditions of only 8 feet of wheel height and a flight path angle of 0.60° (or a change of flight path angle of about six to one) would suggest a guidance means for assuring the pilot that his wheels are clearing the ground throughout the flare. The landings are all excellent and the touchdown scatter is low as compared to the runway length.

The terminal angle (just prior to touchdown) of the F-101 is lower than that of jet transports--about 0.30° --probably because this type of aircraft requires approach speeds 50 percent higher.

These measurements generally confirm those of the WPAFB data taken in 1960. It is obvious that photo-measurements should be taken in greater detail, under more controlled conditions, and with a greater variety of aircraft including the F-111, so that a more statistically significant sample is available.

Figure 3 illustrates some of the critical dimensions and their descriptive terms. Standardization on a set of similar terms is essential for pilots, guidance, flight control, and administrative personnel who must all communicate on these matters.

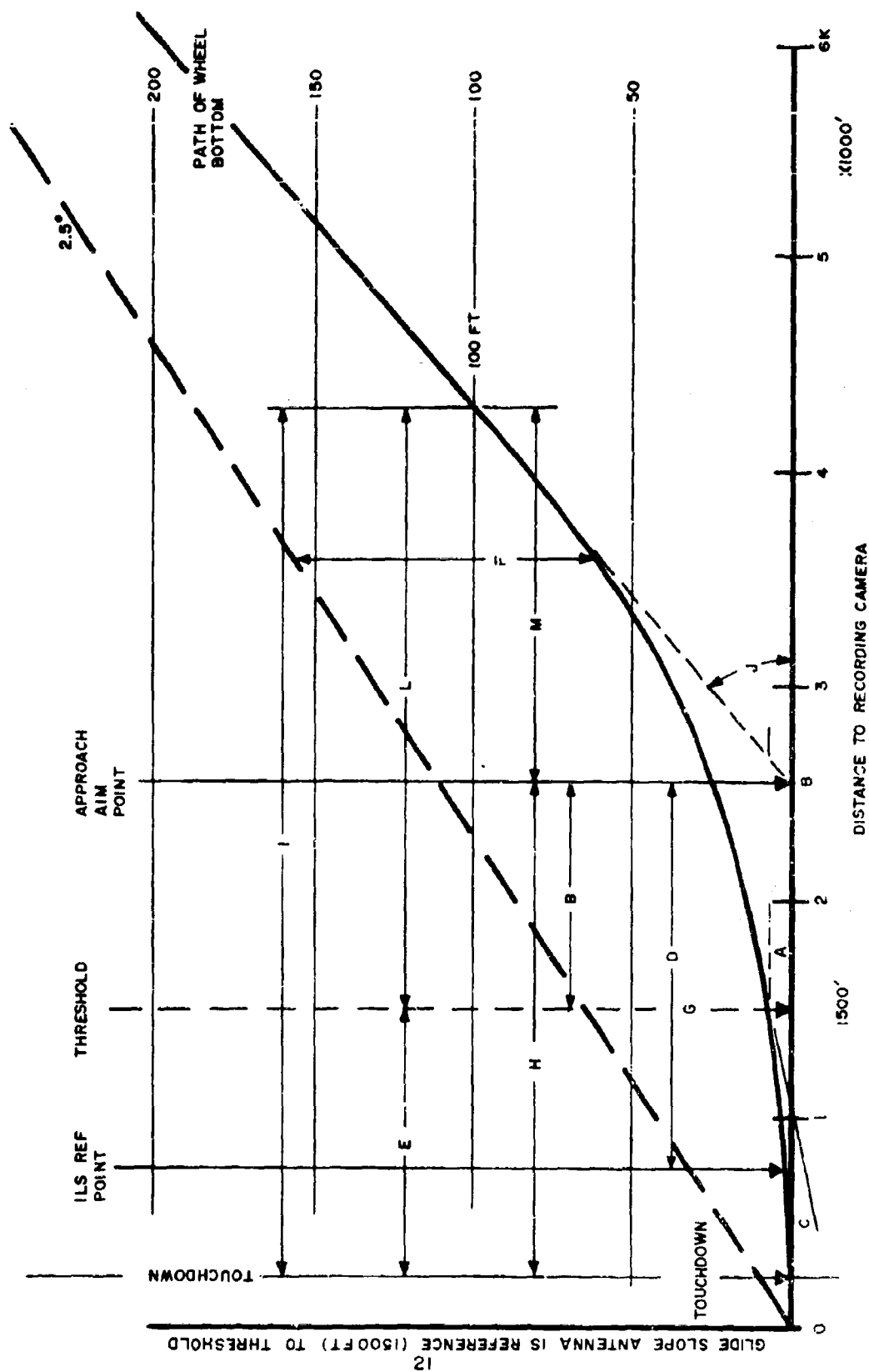


FIGURE 2. AVERAGE FOR FOUR LANDING MEASUREMENTS - F-101

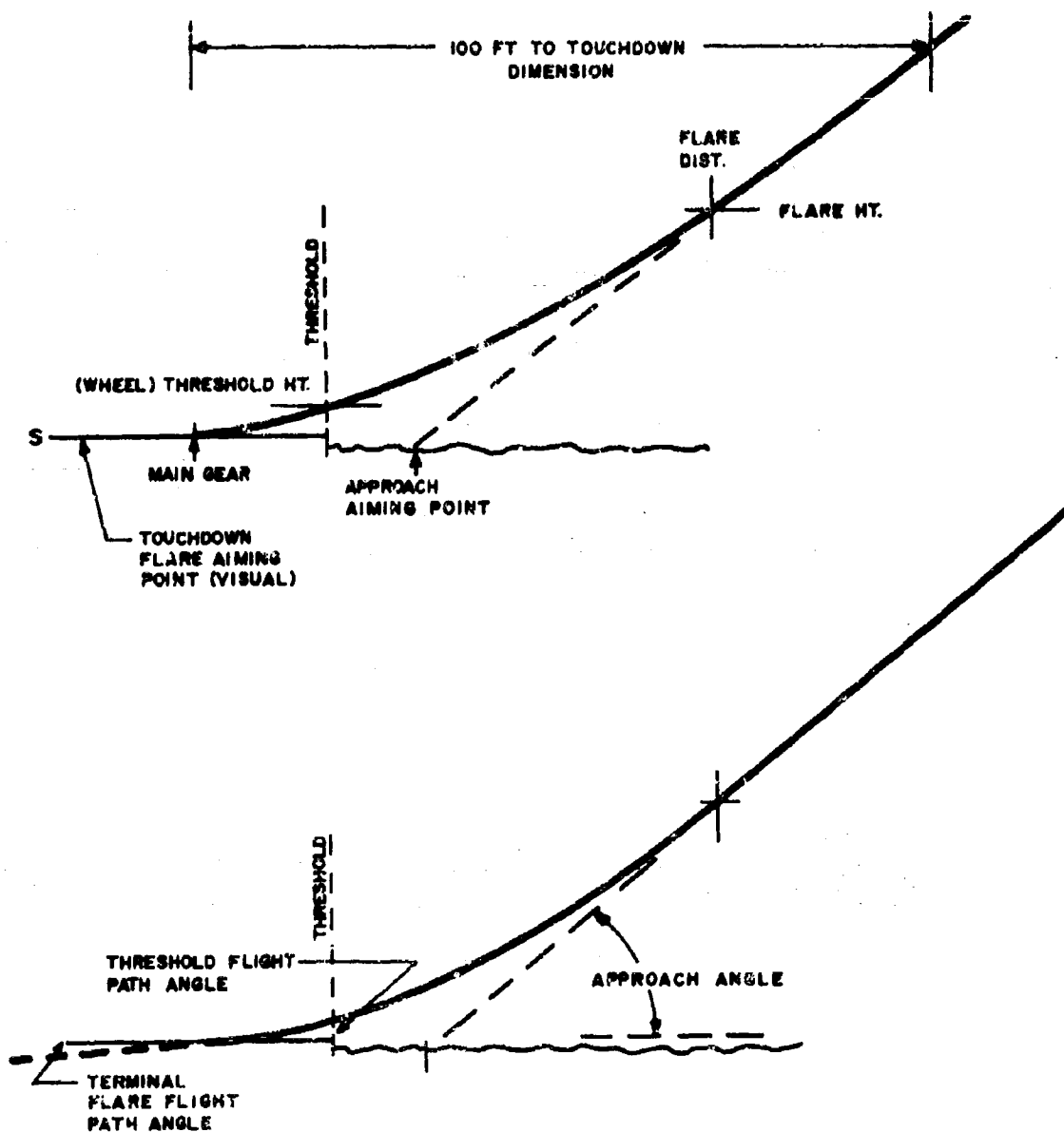


FIGURE 3. CRITICAL DIMENSIONS FOR LANDING SYSTEM DESIGN

TABLE II
SIGNIFICANT LANDING DIMENSIONS

	Operations				Average of 4 observa- tions
	1	2	3	4	
Threshold wheel height in feet	(A) 9	8	9	5	7.8
Approach Aim point (wheel bottom) in feet	(B) 1150	1050	700	1250 before runway	1040
Threshold Flight Path Angle in degrees	(C) 0.65	0.60	0.75	0.40	0.60
Approach Aim point to ILS Reference point (wheel bottom) in feet	(D) 2100	2000	1650	2300	2000
Touchdown distance from Runway Threshold in feet	(E) 800	1350	1700	1150	1250
Maximum deviation below ILS Glide Slope (assume 2.5° and 10-foot antenna to wheel bottom) in feet	(F) 75	75	40	95	71
Distance below path at Threshold (above assumptions) in feet	(G) 47	45	30	48	42
Approach Aim Point to touchdown in feet	(H) 1800	2400	2300	2400	2200
100-foot approach height to touchdown in feet	(I) 3400	4100	4300	4200	4000
Final Approach Flight Path Angle before flare in degrees	(J) 3.75	3.40	3.0	3.0	3.30
Ratio of Approach to Threshold flight path angle	6.6/1	5.7/1	4.0/1	7.5/1	6/1
Terminal touchdown angle based on last 500 feet before touchdown in degrees	0.43	0.30	0.30	0.25	0.32
Ratio of Threshold path to touchdown flight path angles	1.5/1	2.0/1	2.5/1	1.6/1	1.9/1
Final approach path angle to terminal (touchdown) angle	10/1	11/1	10/1	12/1	11/1
100-foot height to approach aim point	(M) 1500	1620	-	1800	1640
Number of points establishing approach-landing trajectory	6	5	8	6	
100-foot height to runway threshold	(L) 2500	2750	-	3050	2800

Estimated accuracy of observations is 5%, F-101 landing on Runway 23
Suffolk County AFB, 4-18-66.

The table below shows the elevation angle of the aircraft as measured from the observation point, 1500 feet from the threshold (ILS glide slope). It is very instructive. Note the initial glide slope angle of 2.5° (beyond 2 miles), reducing to about half this at around 3400 feet. Near the threshold, the aircraft is less than 0.5° in elevation above the threshold elevation. There is a slope upward at this site (toward threshold), and data from about a mile out is referenced to it. The wheels above the runway are used as reference points for these angles.

<u>Vertical angle in degrees</u>	<u>Estimated Range in feet</u>
2.50	Beyond 12,000
2.40	12,000
2.20	7,300
1.90	5,500
1.55	4,400
1.20	3,300
0.80	2,700
0.42	1,800
0.20	1,200

Vertical angle and estimated distance of aircraft from the ILS reference (glide slope): 1500 feet from threshold. Accuracy is about 5% using simplified photo observation and measuring techniques. Data from Runway 23, Suffolk County AFB, Second Fighter Interceptor Squadron, 4-25-66, F-101 aircraft returning from normal mission.

Because of frequent barrier engagements and other problems associated with the landing of a high-performance fighter, considerable emphasis is placed on safe, but early touchdown. The target at the second Fighter Interceptor Squadron, Suffolk County AFB (ADC) is around 1000 to 1200 feet. Figure 4 illustrates how well this is achieved during forty-five landings from operational missions. As will be noted, this agrees well with the 1200 to 1500 foot touchdown point for heavy jet transports. It is likely that even under the best controlled conditions that it will be difficult to reduce this number to much less than 800 feet.

However, if a pilot does not increase his sink rate after visual breakout from an IFR approach, he is apt to land around 3000 feet from threshold. A guidance system designed and installed so that the sink rate below 300 feet is not increased is essential before current 300-foot operational ceilings are lowered.

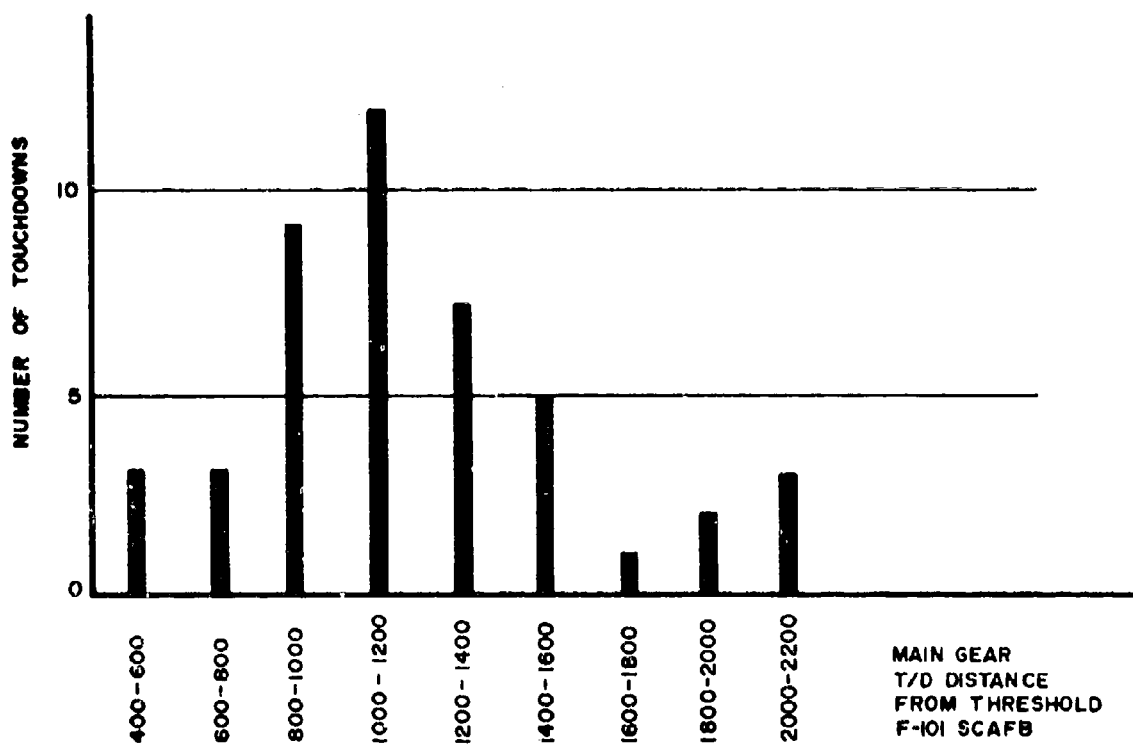


FIGURE 4. DISTRIBUTION OF TOUCHDOWN POINTS

3. LANDING MEASUREMENTS OF JET TRANSPORTS

As noted elsewhere, the large Air Force and DOD emphasis on rapid and large-scale airlift capacity to nearly any point in the world makes the landing trajectory of jet transports of direct tactical significance. The following data from FAA measurements should be confirmed for tactical application under airlift landing environments and for several airlift-type aircraft. It is presented here, however, since some of these aircraft are apt to have similar characteristics. Figure 5 illustrates the arithmetical mean of about 170 measured landings. Note that, though the F-101 passed over threshold at a wheel height of 7 to 10 feet, the jet transports pass over threshold at around 20 feet.

To give some idea of the distribution of these landing parameters, Figure 6 represents the median (50% above and 50% below) line--that is, the 25% and 75% lines. This shows, for example, that half of the landings are from threshold heights of between 13 and 26 feet. Also note that even in this case, 25% of the landings have threshold heights of less than 13 feet.

Table III is reproduced from the FAA report to give examples of the kind of quantitative data needed in detail for many types of Air Force aircraft under various tactical, airlift and related conditions. It is shown in various parts of this report that such data is essential to the design of tactical landing guidance equipment.

Although Figures 5 and 6 and Table III represent IFR data, all landings under IFR are to a visual contact height which legally means a "see-to-land" condition. Consequently, VFR practices and conditions are still very significant even under CAT I, II, and probably CAT IIIA conditions. An FAA study is now under way to correlate VFR and IFR landing data under Civil conditions.

SOURCE:

"STATISTICAL PRESENTATION OF
OPERATIONAL LANDING PARAMETERS
FOR TRANSPORT JET AIRLINES" FAA
FLIGHT STANDARDS, JUNE 1962

UNLESS OTHERWISE NOTED:
DIMENSIONS ARE IN FEET

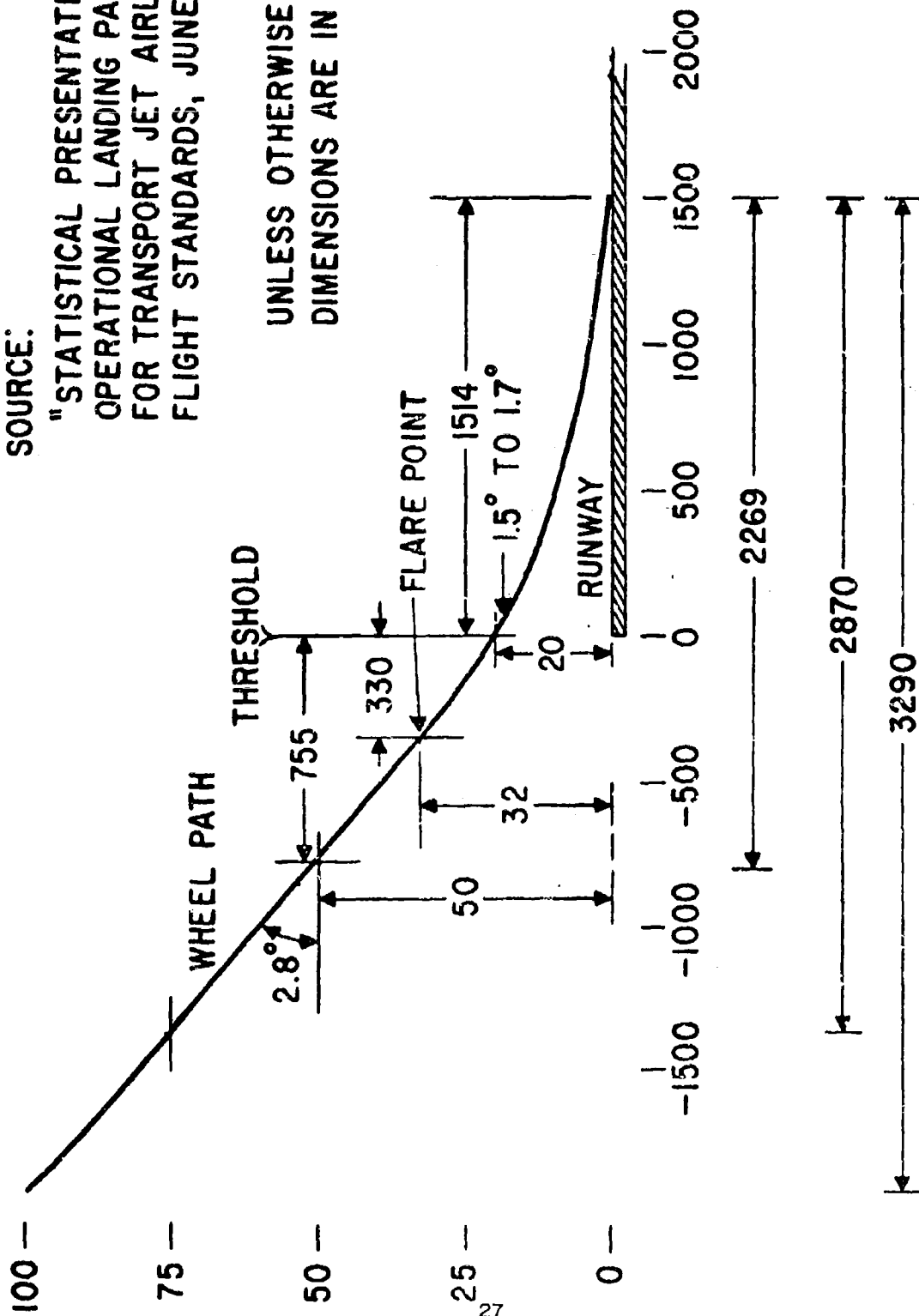


FIGURE 5. MEAN VALUE OF JET FLARE GEOMETRY

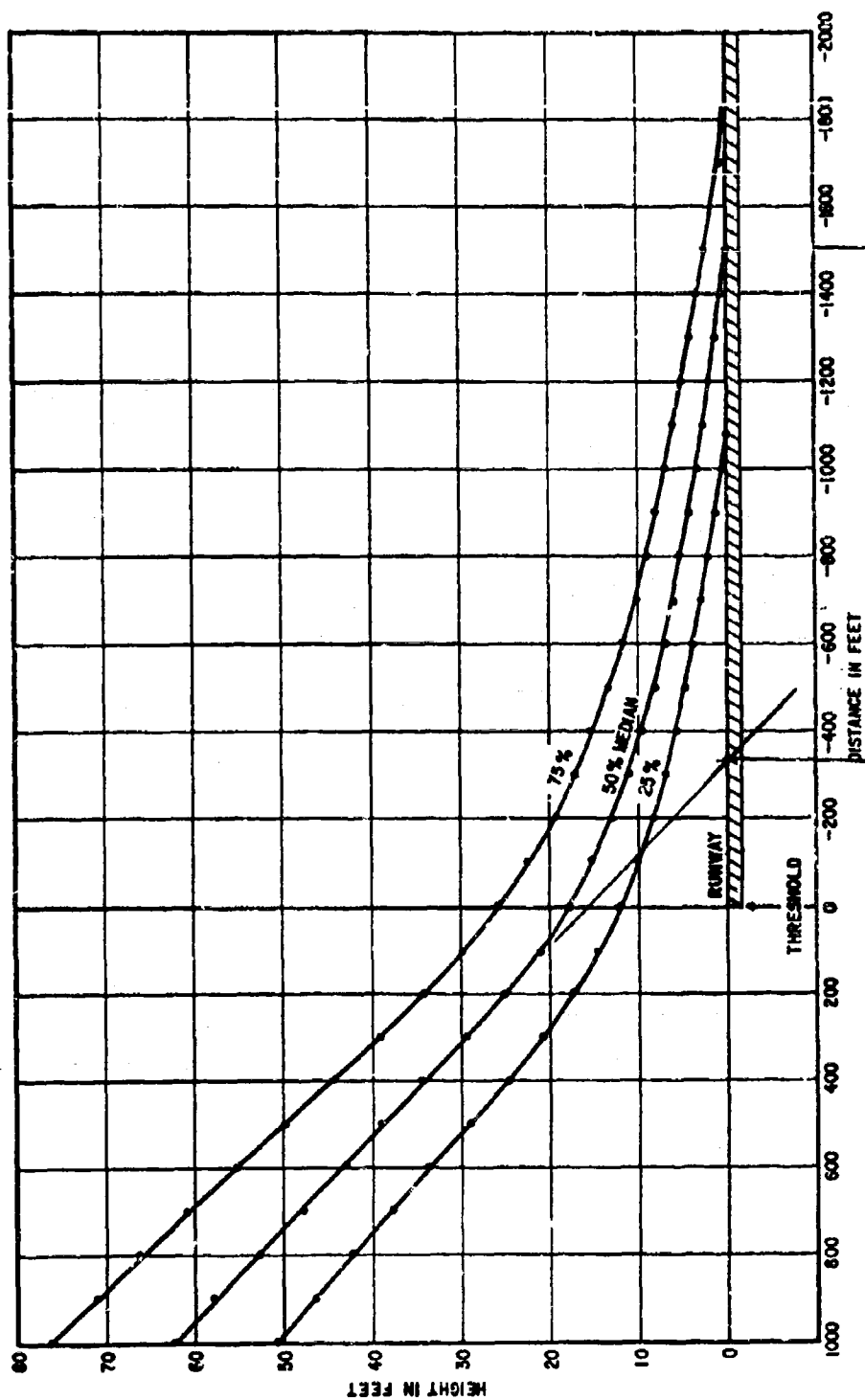


FIGURE 6. HEIGHT DISTRIBUTION VS. DISTANCE IN 168 VFR LANDINGS
(FAA JUNE 1962)

TABLE III

OBSERVED DATA AT CHICAGO

Landing No.	Aircraft	Weight in 1000 lbs.	V ₀ Still Speed (kts)	Approach Angle		Distance to Threshold (ft)	Flare-Point		Threshold, (ft)			Main Gear Touchdown, (ft)		Brakeoff		Base Wheel Down From Touchdown		Spillers Up from Touchdown	
				°	Ratio $\frac{W}{S}$ 3.0		Dist. to Threshold (feet)	Height (feet)	Weight		Speed, V ₀ (kts)	Distance, Ft. From (ft)	From 50% (kts)	Speed, V ₀ (kts)	Ratio $\frac{W}{S}$ 3.0	Dist., (ft.)	Time (Sec.)	Dist., (ft.)	Time (Sec.)
									Feet 50	Pt. 50									
14	B-720	163.9	95.8	2.5	.83	1290	250	36.0	8.5	.17	131.0	646	1936	130.7	1.36	87	0.39	---	---
15	DC-8	170.0	98.5	2.4	.80	1420	-200	24.0	32.5	.65	127.1	1601	2221	126.4	1.18	---	---	---	---
16	B-707	167.3	104.1	2.6	.97	880	400	28.5	13.0	.26	116.9	1333	2213	131.7	1.26	478	2.05	---	---
17	DC-8	169.6	92.7	2.9	.87	580	260	34.0	24.0	.18	116.9	1773	2353	105.8	1.11	768	4.27	---	---
18	CV-880	---	---	2.1	.70	1140	500	19.5	8.5	.17	111.2	988	2388	124.4	---	925	4.29	---	---
19	CV-880	113.8	101.7	2.9	.97	900	440	32.0	12.5	.25	137.0	1355	1753	134.7	1.32	612	2.63	---	---
20	DC-8	182.6	96.1	1.5	1.17	800	310	20.5	8.0	.16	123.2	1346	1686	125.8	1.31	818	1.71	---	---
21	B-720B	157.5	97.7	2.7	.90	660	470	41.5	23.5	.17	116.6	1418	1078	125.8	1.29	471	2.01	---	---
22	B-707	159.5	101.9	1.6	.53	1110	-200	13.0	18.5	.37	136.2	1693	2833	129.8	1.27	621	2.71	---	---
36	B-707	138.0	95.0	1.9	.63	560	200	36.0	12.0	.64	127.7	1611	2171	123.1	1.30	---	---	---	---
37	B-720	164.3	96.2	2.1	.70	960	300	25.5	16.5	.33	131.3	1366	1704	126.5	1.32	---	---	---	---
38	B-720B	171.4	101.9	3.1	1.10	1650	1100	42.5	15.5	.33	135.3	2019	3669	127.3	1.25	---	---	---	---
39	B-720	153.5	93.0	4.3	1.43	810	1060	66.0	10.5	.21	128.9	915	1725	125.5	1.35	775	3.60	---	---
40	CV-880	117.4	102.7	3.6	1.20	790	780	49.5	17.5	.35	139.6	1343	2133	133.3	1.30	727	3.23	---	---
41	DC-8	---	---	2.7	.90	1150	1270	53.0	15.0	.30	120.3	1562	2712	113.4	---	1008	5.20	---	---
42	B-707	170.0	107.0	3.0	1.00	560	1100	74.5	30.5	.61	149.2	2574	3134	138.3	1.29	---	---	---	---
43	CV-880	124.6	106.2	2.4	.80	510	240	39.0	30.5	.61	140.1	2269	2759	130.9	1.23	583	2.50	---	---
44	B-720B	168.0	100.8	2.6	.87	790	890	53.5	23.5	.47	120.2	1885	2675	121.0	1.20	413	1.93	---	---
45	B-720B	170.2	101.5	2.1	.70	550	100	33.5	10.0	.60	132.3	2518	3068	124.8	1.23	1136	5.23	---	---
46	CV-880	121.3	104.6	1.7	.57	1140	500	22.0	10.0	.20	134.2	977	2417	126.5	1.23	567	2.52	---	---
47	CV-880	131.0	109.0	1.7	.57	1210	170	19.0	15.0	.30	136.5	1652	2832	126.7	1.16	1172	5.41	---	---
48	CV-880	---	---	2.1	.77	1160	800	35.5	13.5	.27	129.6	1472	2612	127.7	---	543	2.15	---	---
49	DC-8	178.0	99.0	2.6	.87	1000	170	26.0	12.5	.25	127.3	1619	2619	117.5	1.19	578	2.82	---	---
50	DC-8	170.0	96.0	4.2	1.40	707	1010	68.5	18.5	.37	119.6	1487	2187	112.1	1.17	1405	7.34	---	---
51	CV-880	119.8	101.5	2.2	.73	790	120	24.5	20.5	.41	138.1	1258	2078	129.4	1.25	1305	6.11	---	---
52	DC-8	---	---	2.6	.83	1020	590	32.0	13.5	.27	127.7	1715	2735	122.0	---	956	4.70	---	---
53	CV-880	124.7	106.1	1.5	1.17	1360	1300	47.0	11.0	.22	142.7	1737	3557	128.3	1.21	1591	7.66	---	---
54	DC-8	185.9	97.6	2.8	.93	670	220	27.0	34.0	.38	124.4	2294	2964	121.7	1.25	1616	7.99	---	---
55	B-720	114.5	91.2	2.8	.93	700	400	35.0	19.0	.38	126.4	1399	2699	120.1	1.32	961	4.75	---	---
56	B-720	115.8	90.3	2.9	.96	700	350	32.5	18.5	.37	126.9	1406	2406	122.3	1.35	1432	3.16	---	---
57	DC-8	174.6	97.9	3.3	1.10	1110	920	37.0	7.0	.14	123.1	1738	1818	117.7	1.20	673	3.36	---	---
58	B-720	141.0	89.5	2.2	.71	1300	710	27.0	6.5	.13	125.7	1462	1602	125.2	1.41	---	---	---	---
59	B-707	115.0	37.0	2.9	.91	1070	780	38.0	12.0	.24	136.0	1015	2015	131.4	1.35	1282	6.21	---	---

4. LANDING MEASUREMENTS OF LARGE HELICOPTERS

Figures 7 - 10 illustrate both the vertical and horizontal flight path of a V-107 (CH-46) operating into a small landing pad (85 x 85 feet) at the end of a pier on the East River in New York City. Although the operation of these large helicopters (25 passengers) from a small roof top 800 feet above the streets of Manhattan is also significant, the shipping traffic, bridges, lack of overshoot clearance, etc., probably make the water level landing operation just as demanding. The typical cleared landing area for heliports or pads is often less than 200 feet and sometimes is even less than 100 feet. The landing is a descent on a steep path (8.5°) in Figure 7, to a hover position about 5 to 10 feet above the surface with a nose high attitude. The main gear touches down, and then the nose gear is slowly lowered sometimes after a short taxi roll is started.

The horizontal flight path for most fixed-wing aircraft even in VFR is essentially a straight line for the last mile or two since maneuvering and side-step corrections are at higher speeds and the aircraft are far less responsive than a helicopter. Figures 8 and 10 illustrate the curved flight path into the landing, one terminating in a straight run for about 800 feet and the other continuing to curve almost to touchdown. In IFR it is likely that some restraints on horizontal paths can be imposed without serious drawbacks. Retention of steep descent paths often makes it possible to arrive near the landing point from angles other than a localizer direction. Steepness of angle helps also on visually establishing the landing point--an old guide line used in dive bombing, shallow angles result in poor target visibility.

By comparing the vertical and horizontal flight paths it is also noted that even though curving in the horizontal, a good constant descent angle is maintained in the vertical plane. From the guidance viewpoint, rather wide lateral coverage is needed. Selectable glide paths (shallow, steep without denying normal glide angles) appear desirable. It is likely that the sensitivity with vertical path angle should be varied. A study similar to this one for ECOM (Avionics Lab) discussing only these variables for the tactical use of helicopters indicated wide course widths are desirable at steeper angles.

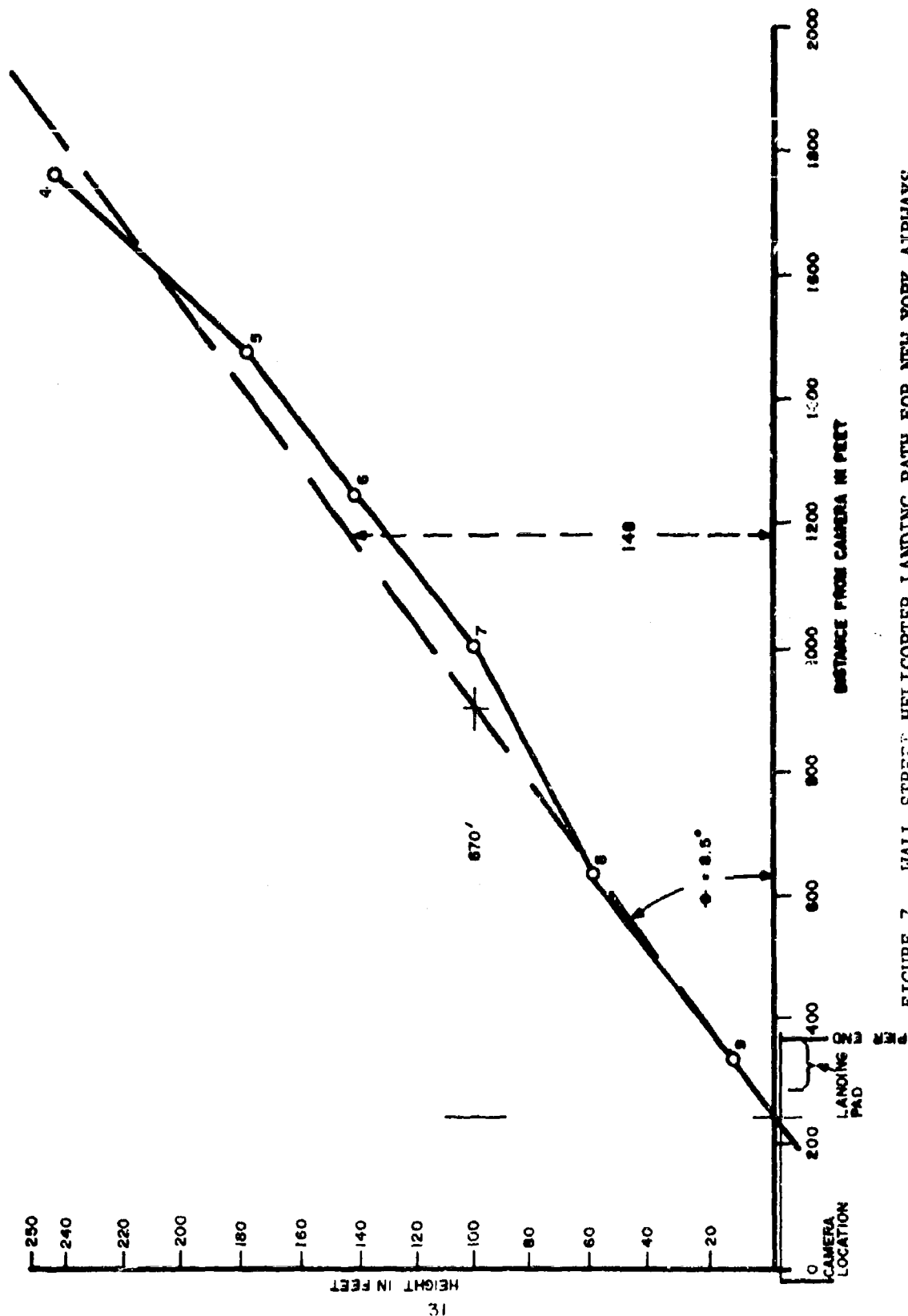


FIGURE 7. WALL STREET HELICOPTER LANDING PATH FOR NEW YORK AIRWAYS
V-107 (Vertical) - LANDING NO. 1

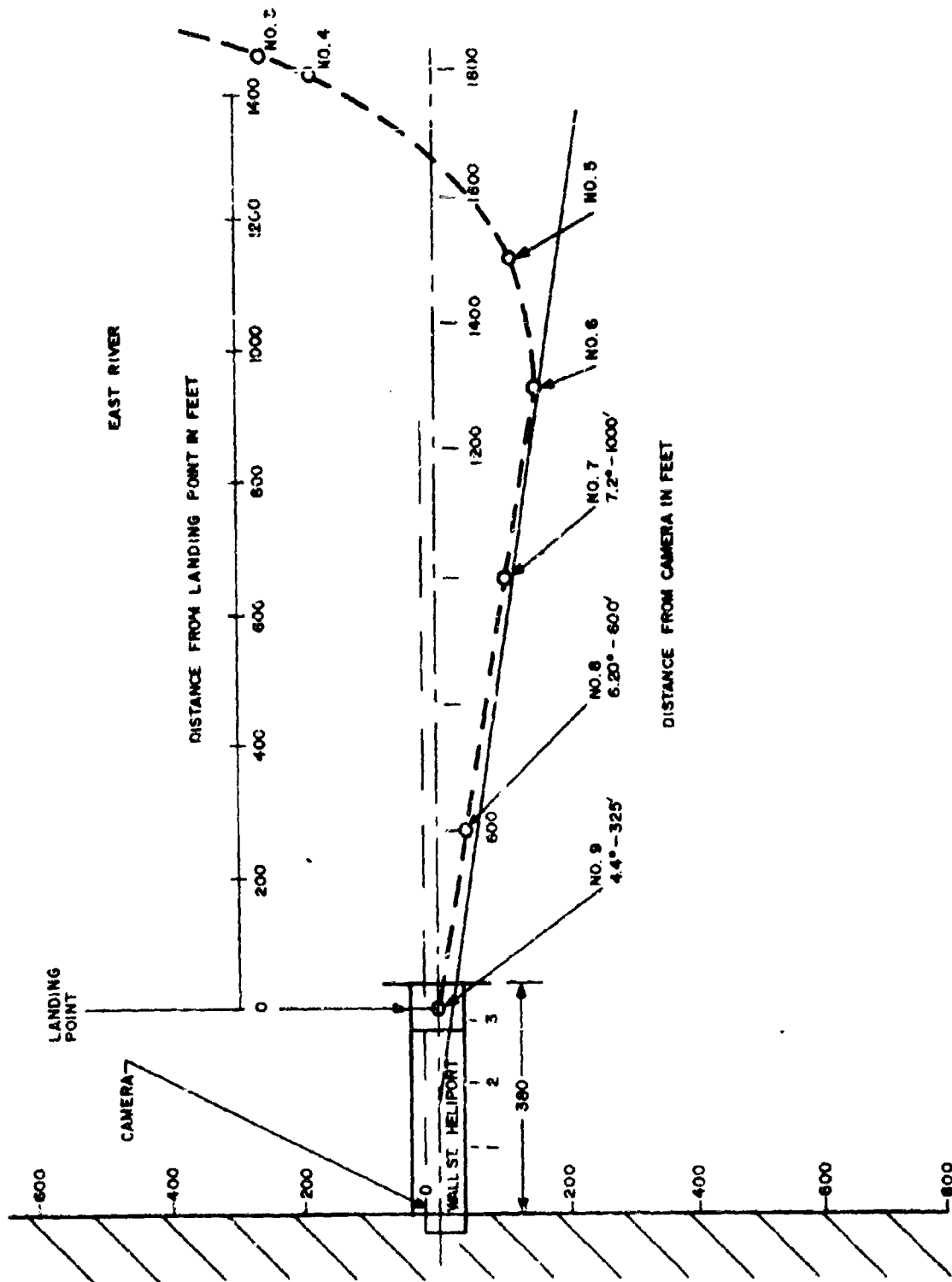


FIGURE 8. WALL STREET HELICOPTER LANDING PATH FOR NEW YORK AIRWAYS V-107 (Horizontal) - LANDING NO. 2

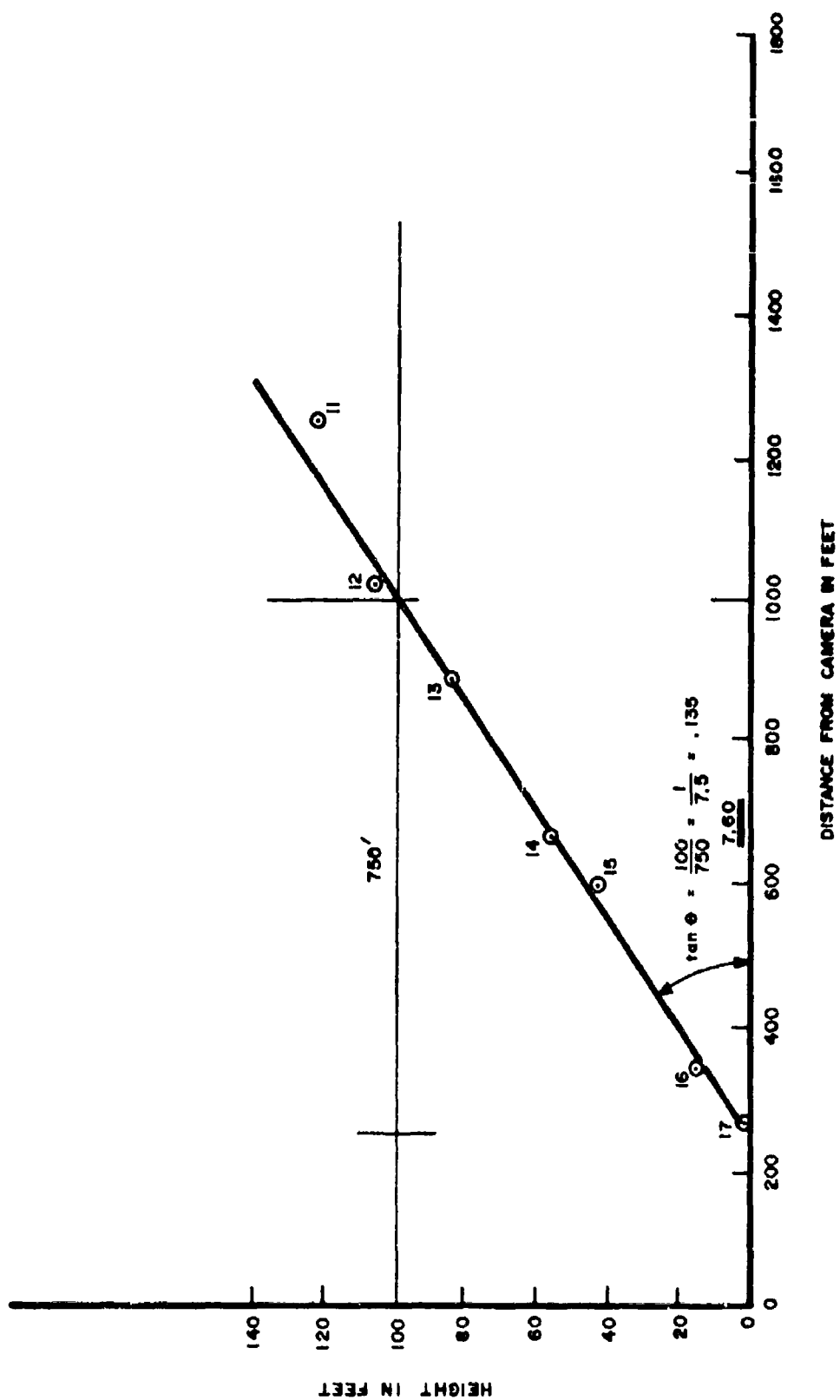


FIGURE 9. WALL STREET HELICOPTER LANDING PATH FOR NEW YORK AIRWAYS
V-107 (Vertical) - LANDING NO. 2

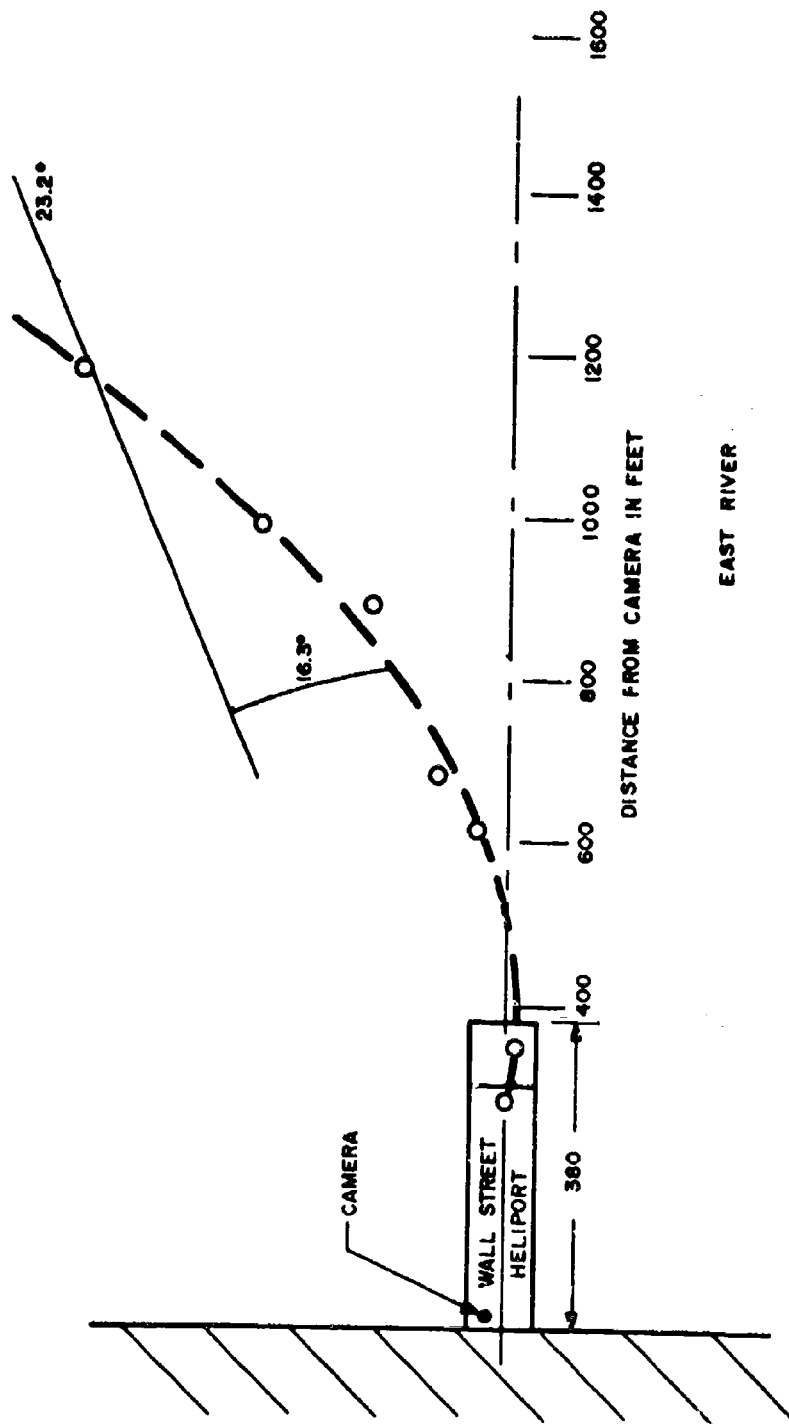


FIGURE 10. WALL STREET HELICOPTER LANDING PATH FOR NEW YORK AIRWAYS
V-107 (Horizontal) - LANDING NO. 2

5. STOL LANDING MEASUREMENTS

The Breguet-941 (McDonnell aircraft) has received considerable attention here and in Europe as a promising example of a large STOL aircraft. The newer models offer considerable potential for battle area airlift, airdrop, and other tactical missions not now achieved as economically or reliably with current aircraft. Thus, the STOL data is noted since during the life time of a tactical landing system it is desirable that such aircraft also be accommodated. Although it is possible with a helicopter (under certain conditions) to negotiate angles up to 30 degrees of descent path, the large STOL will probably operate around 5 to 10 degrees and can use the equipments developed for steep flight path angles of helicopters. A test of the Breguet-941 at Washington's Dulles Airport, utilizing typical approach and climb profiles is shown in Figure 11. Perhaps a fixed path around 7 to 9 degrees with wider than normal course widths might suffice. Again, more detailed data should be taken on this aircraft in various configurations and environments to determine the flight path characteristics, etc.

It should be noted that the helicopter can slow to around 30 to 50 knots requiring little roll-out, whereas the large STOL may approach in the 50 to 70 knot region requiring roll-out of perhaps 500 to 1000 feet depending on weight, thrust, and clearance criteria. This latter characteristic will probably call for different localizer placement criteria than for landing of helicopters. Both aircraft types will probably need separate glide path and localizer sites for optimization of their respective landing distances. A major tactical justification for such vehicles is short landings over obstacles. Optimum siting of vertical and horizontal landing guidance is essential to IFR usage. Co-located glide path/localizer units are not always capable of this optimization criteria and, when used, IFR landing restriction must reflect this matter. The relationship of landing path dimensions relative to the location of the vertical and horizontal guidance sites and the available landing strip dimensions is a critical aspect of system design. More definitive standards are urgently needed for landing system designers.

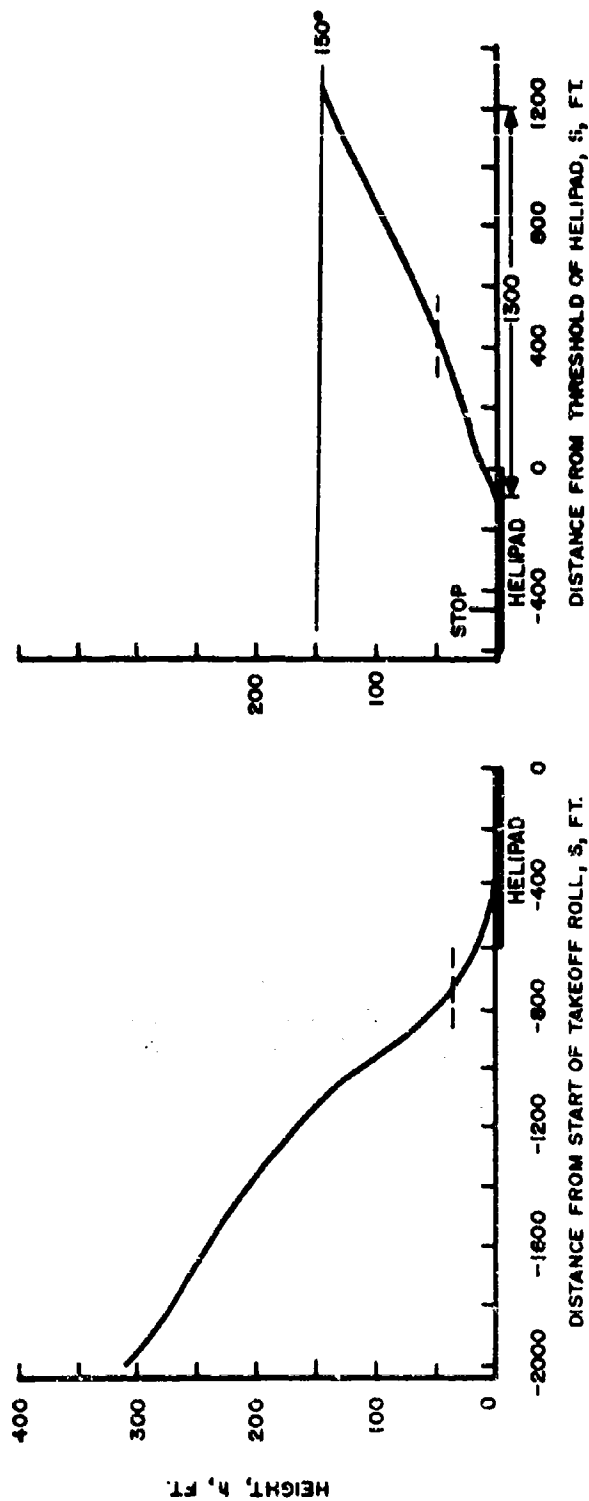


FIGURE 11. SAMPLE ALTITUDE DISTANCE PROFILES FOR TAKEOFF-CLIMBOUT AND LANDING APPROACH AS OBTAINED FROM FAIRCHILD CAMERA (Breguet 941)

6. WADC LANDING MEASUREMENTS

Since the WADC report is brief and clearly confirms the more detailed data of the F-101 measurements, it is reproduced in this report as Appendix A with some underlining added for emphasis of certain points. Basically, the ILS standards (GPIP) cause the fighter type aircraft to land up to 2400 feet beyond GPIP or about 3000 feet from touchdown. As noted, pilots flying operational aircraft do not tolerate this. They abandon the glide path, (VASI, GCA or ILS--they are all sighted about the same) and "duck-under" to achieve a safer touchdown distance about 1000 feet from threshold.

If this touchdown is achieved without increase in sink rate, the approach aiming point needs to be moved about 2000 feet forward from its present position for these aircraft. The transport types do not seem as demanding, but it is probably true that an approach aiming point about 1000 feet forward from present standards would be more suitable for them. The flight approach to the forward or "relocated" (GPIP-ILS reference points) aim point permits a shallow flare with an always decreasing sink rate near the ground.

The fact that most pilots of jet aircraft abandon the glide path and fly beneath it in IFR operations is being recognized as one of the basic limitations to the solution of low visibility landing problems. The value of any electronic, visual or other landing guidance system, is minimized if this problem is ignored. "Duck-under" maneuvers need more thorough investigation since it is likely that with high-performance aircraft a realistic ceiling today is around 300 feet, yet with adequate aim points to match the aircraft performance it is possible that the current objectives of 100 feet to one quarter mile can be realized. Whether pilot training, aircraft characteristics, or other factors can change this situation can be determined only by an extensive Air Force landing measurements program.

The impact of the "duck-under" maneuver is illustrated in Figure 12. These sink velocities for different departure heights are related to approach speeds of about 120 to 130 knots. For many Air Force aircraft near the 170 to 195 knot approach speed, the associated sink rates are obviously greater. With sink rates of 2000 rpm possible (below heights of 200 feet), it is imperative that a resolution of this problem be undertaken soon. Air safety studies indicate that in the case of the Century Series Aircraft and supersonic bombers (B-58) many fatal landing accidents can be related to the "duck-under" maneuver. Often ILS, GCA, and VASIS are used for VFR. The same problem appears to exist as in IFR.

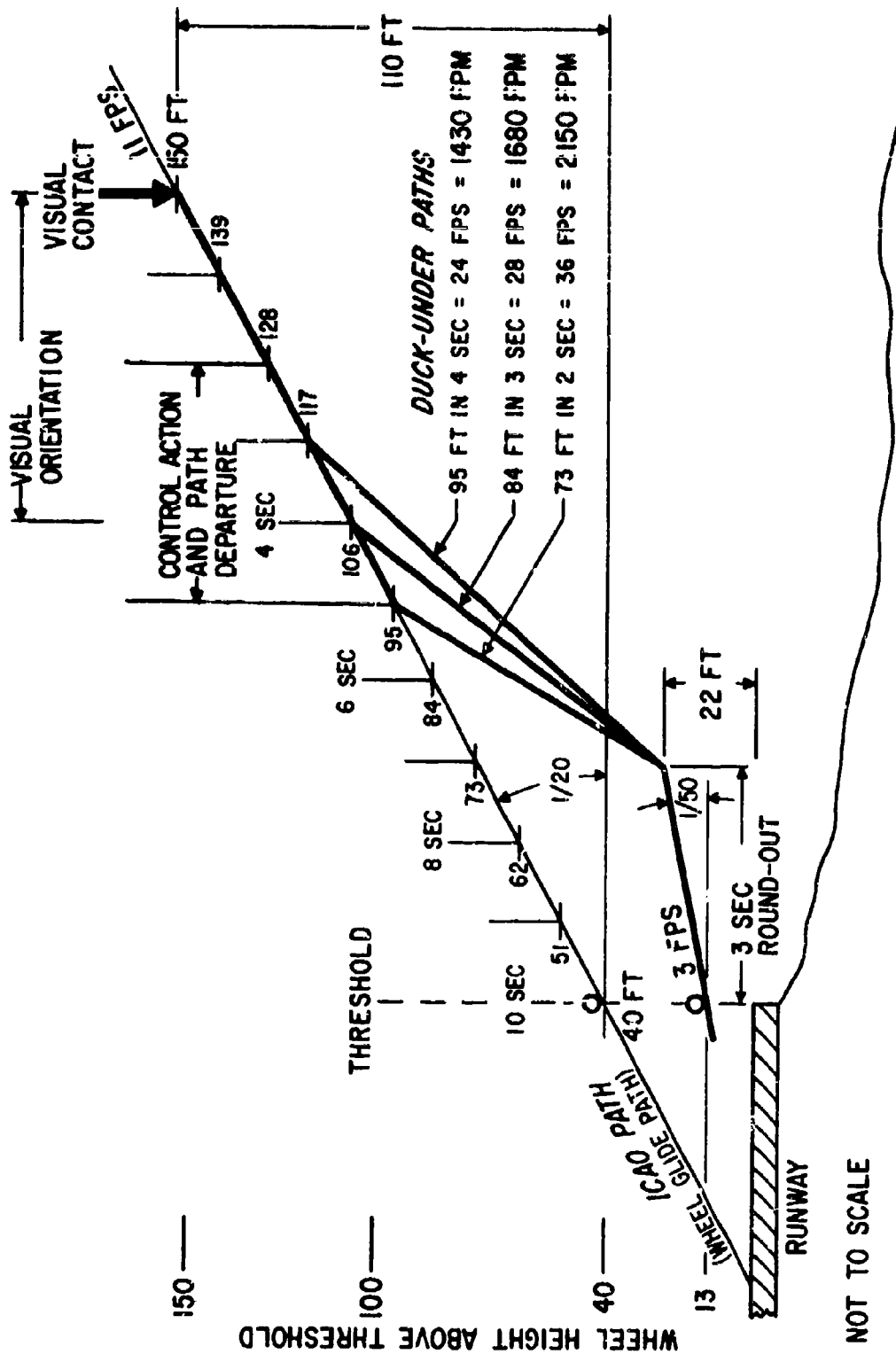


FIGURE 12. IFR DUCK-UNDER MANEUVER FROM 150-FOOT VISUAL CONTACT

The risk comes when the pilot, not realizing that he has increased sink rate (since he often looks out the windshield away from his instruments) upon first sign of visual contact, strikes short of the runway. He cannot reduce the high vertical velocity he has inadvertently built up so near the ground. Pilots have no training in such a maneuver and little low visibility experience. The pilot is essentially on "his own" with little assistance from radio guidance. It is often argued that relocating the GPIIP forward of its present location would simply invite striking the ground short of the runway. This is not the case if sink rate is positively decreased. Such a maneuver elongates the flight path and places the aircraft over the paving. It is an illusion not readily recognized, yet readily amenable to scientific approach and solution.

Unfortunately, the young pilot in the process of becoming trained for IFR flight is not properly advised of these critical matters. AF Manual 51-37 issued in January 1966 stated in Chapter 18, "Landing from Instrument Approaches."

"When the time for transition to visual flight conditions is very brief, there is a tendency for the pilot, upon sighting the runway, to reduce power rapidly and live toward the runway. THIS TENDENCY MUST BE AVOIDED. Even though the approach angle may be higher or lower than when making a visual approach, make a gradual flare out by reducing the power smoothly and avoid abrupt changes in attitude or power."

With respect to VASI (optical glide path) the manual states: "However, the VASI will bring the pilot through a "gate" at the threshold where he may accomplish normal flare and landing." The VASI, ILS, and GCA use essentially the same (mislocated) GPIIP or approach aim point.

It is interesting to note that the "duck-under" maneuver is recognized. However, the Air Force solution should be more than an admonition to the pilot that, "this tendency should be avoided." In fact, if this advice is followed explicitly, the aircraft will overfly the amount of runway indicated in the WADC report of 1960. Why this obvious hazard has not been recognized and corrected during the several subsequent years is probably due to the lack of communications. The ADC and SAC USAFE safety staffs have been pointing this out for the past 3 to 4 years, yet the methodology of investigating, testing, and modernizing the training manual so that it is up to date has not taken place. This problem itself (GPIIP-duck-under) would warrant a sizable project effort seeking its elimination.

7. LANDING MEASUREMENT TECHNIQUES

As indicated elsewhere in this report, it will be impossible to resolve the Air Force landing problems and develop a suitable low visibility landing system without a full understanding of the problem. This will come about by first carefully examining and understanding the details of the landing maneuver. All three axes must be examined at heights of from 300 feet to touchdown for the varied aircraft types and environments of the Air Force. This could be a costly undertaking, yet it is essential to the success of a far more costly equipment procurement program.

An economical means of measuring these data at operational bases and a low cost (per landing) so that statistically significant samples are available, is to use a photographic recording system, near the GPIF. By directing a camera field of view essentially "up," the intended glide-path trajectory measurement is simplified. Many points of a given trajectory become available with a 16-mm movie camera and film. The photo results are analyzed with calibration points recorded simultaneously on the film with the flight path.

Utilizing a film reader, the film processing per landing (to obtain data for later processing in a computer) is achieved by reading about 5 significant measurements from the film in each direction. Figure 13 is a reproduction of a typical frame of such a film showing the clock (1 rotation per 0.5 second and angular calibration devices readable to about 0.01 degree). The computer utilizing angles "triangulates" the known dimensions of the aircraft, thus determining its range height and displacement from centerline. Figures 14 and 15 show the simple steps to measure attitude and position.

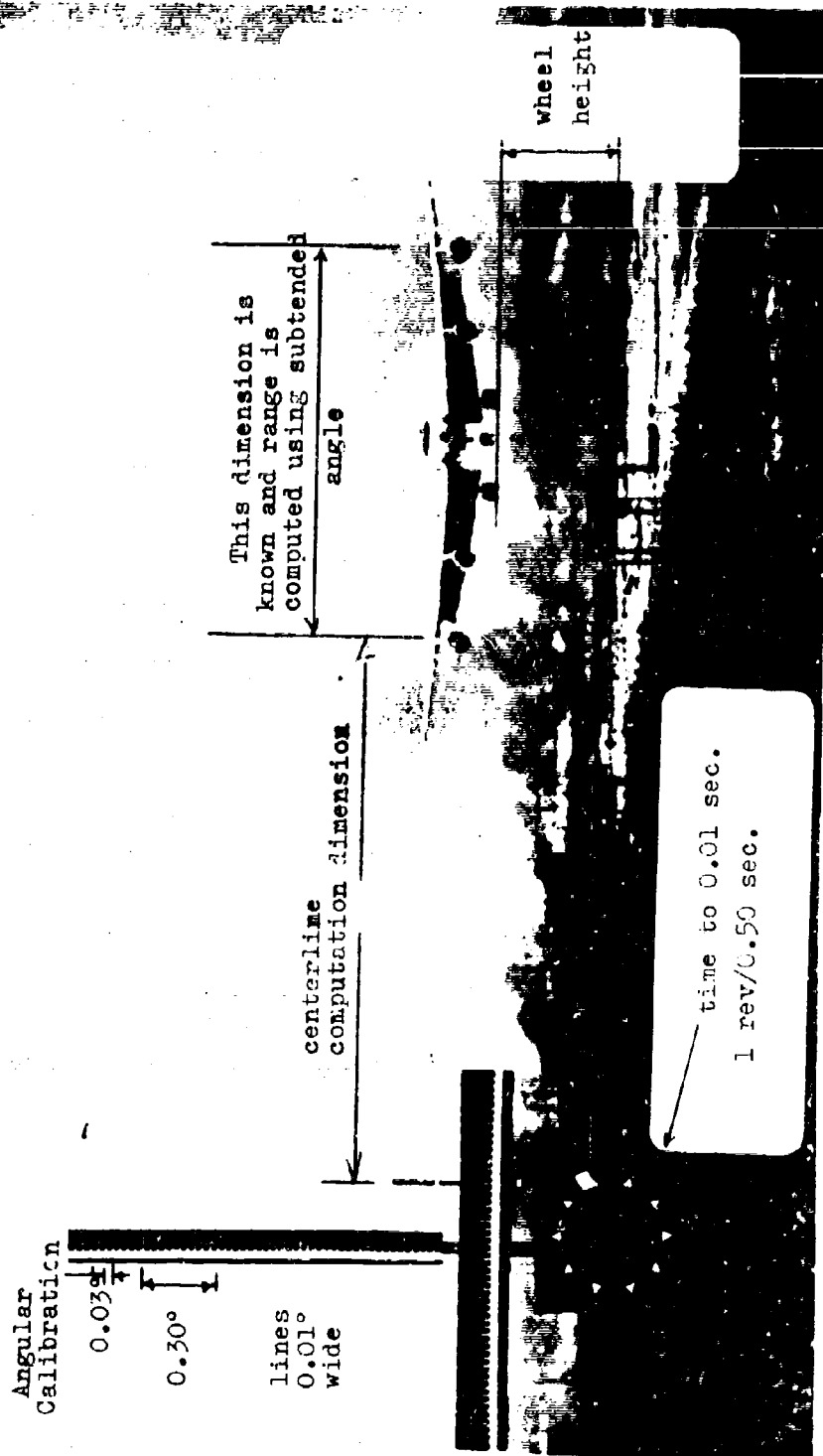
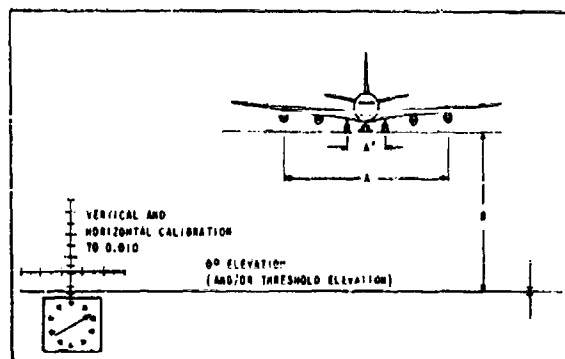


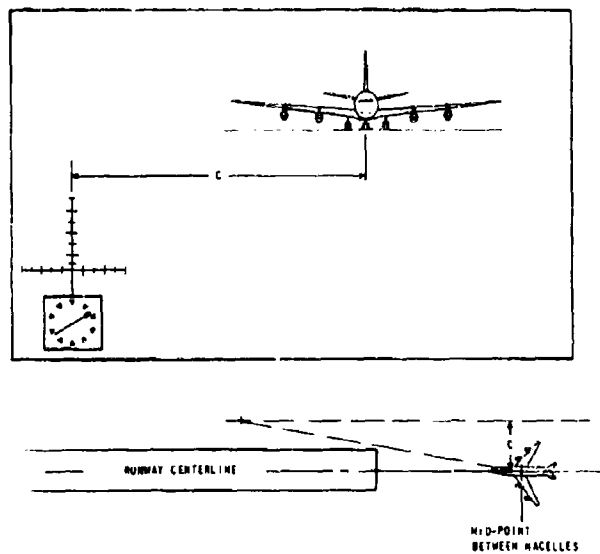
FIGURE 13. TYPICAL FRAME OF PHOTOGRAPHIC MEASUREMENT CAMERA



Step 1: Determine distance of aircraft from camera using dimensions such as A or A'. Special rulers for specific aircraft and dimensions are used. Angular and dimension calibration in film used as reference in projection.

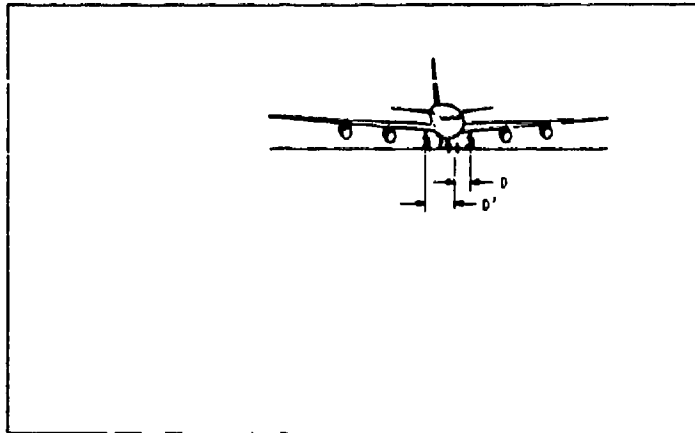
Step 2: Determine wheel height above threshold elevation using dimension B and scale in film. Range and vertical angle is then used to compute height in feet.

SUMMARY OF DATA ANALYSIS PROCEDURE, STEPS 1 AND 2



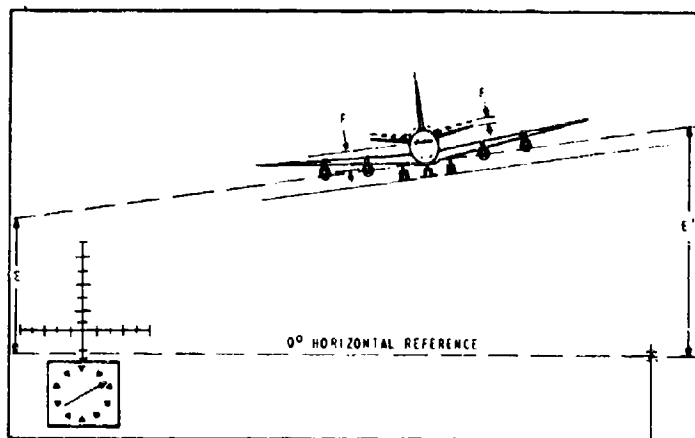
Step 3: Determine dimension C, the displacement of the aircraft from centerline, by locating midpoint of dimension A and scaling to reference mark in film which is parallel to runway centerline. Displacement is computed using results of step 1 (range computation).

FIGURE 14. SUMMARY OF DATA ANALYSIS FOR STEPS 1, 2, and 3



Step 4: Measure dimensions D and D' to establish aircraft axis relative to line between camera and aircraft. Using distance and displacement, establish angle between axis of aircraft and runway centerline.

SUMMARY OF DATA ANALYSIS PROCEDURE, STEP 4



- **Step 5:** Determine roll by measuring E and E' .

Step 6: Determine pitch by noting the position of the Horizontal stabilizer relative to the wing (F and F') or measure distance between bottom of the nose wheel and the main gear. Subtract camera vertical viewing angle to obtain pitch relative to runway.

FIGURE 15. SUMMARY OF DATA ANALYSIS FOR STEPS 4, 5, AND 6

3. THRESHOLD ENVIRONMENTAL CONDITIONS

For over twenty years the radio altimeter has been proposed for the solution of the low visibility landing problem since it can theoretically measure the height of the aircraft. All radio altimeters accomplish this by a directional radio signal reflected back from the ground or water directly beneath the aircraft. One obvious relationship of the landing trajectory measurements projects discussed in this report and a radio altimeter is the fact that from a critical height of 150 to 200 feet, the aircraft may fly forward as much as 5000 to 6000 feet.

Since sink rate is rate of change of height, the flatness and gradient of the reflecting surface beneath the aircraft is essential to the success of such landing devices as radio altimeters. As Figure 16 illustrates, even permanent civil fields do not have repeatable smooth approach profiles to assure the validity of aircraft height measurement. Not only are large, false sink rates generated, but false absolute heights are indicated on many approaches. The objective, of course, is to determine the height of the wheels above touchdown even when the aircraft is still 4000 to 5000 feet from it. For tactical fields, the irregular approach profiles can often be worse. Site selection for runways must be flexible in a tactical environment. This would rule the radio altimeter out for this purpose.

In fact, the safe use of radio altimeters to determine only a 200-foot or 150-foot check point (not a continuous, longitudinal path) is even doubtful because, as seen in Figure 16, there is a great propensity for the terrain to drop away on a negative slope from threshold. This would create a highly hazardous situation since the radio altimeter would measure a height greater than the actual height. In other words the aircraft would be lower than the indicated height.

Thus, a useful example is illustrated by comparing measured landing parameters and runway environments to an electronic landing aid and its tactical worth is evident.

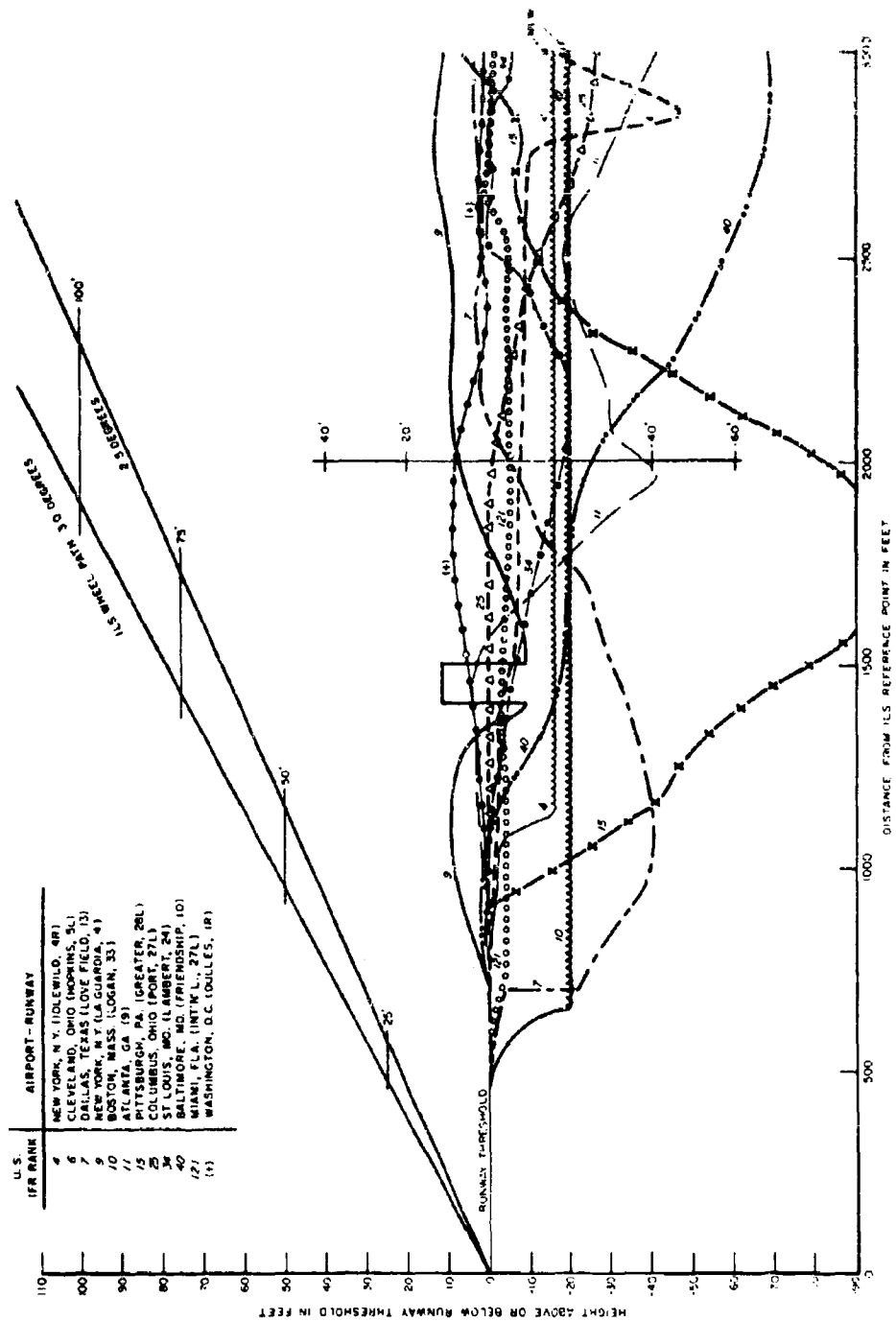


FIGURE 16. APPROACH TERRAIN PROFILES

SECTION III

FUNDAMENTALS OF LANDING GUIDANCE

Although a long history (since about 1935, see reference 99) of landing system development exists, little is recorded that serves as technical guidance for selecting techniques to meet different landing requirements. The requirements differ with aircraft types, missions, nature of landing site, and the visibility conditions. The objective of this section is to abstract this thirty years of technological developments of landing techniques that has seen about thirty systems of one type or another emerge. Many are in the microwave region (S-, C-, K-, and X-bands) and some are modernized versions of the ICAO-ILS, which operates at 110 Mc and 330 Mc. This is not to recount history so much as to establish what has been learned that will aid in determining a tactical landing system design.

The earliest systems of note that may become candidates for the Tactical Landing Program operate in the 110-Mc region. Earlier, constant-intensity glide paths, and LF radio ranges are not considered to be adequate. The SCS-51 landing system of World War II (reference 123) utilizing a five-loop Alford antenna array for the localizer and an earth mirror (reflective) glide slope, typifies the first attempt at a tactical landing system wherein the signal is available directly in the aircraft (as different from GCA). This led to the development of flight instruments and autopilot couplers that could be activated directly from the ground-reinforced signals. The SCS-51 ground system consisted of a K-53 truck and trailer. The airborne signal format was more flexible and useful for flight control than the GCA (reference 99). As a matter of fact, the GCA later adopted the concept by processing the ground radar return signal and re-transmitting it to the aircraft in ILS format for airborne processing and display. This was further pursued in the (Bell) GSN-15 (reference 124), utilizing tracking radars (locked to one target) rather than the scanning beam radars of the Gilfillan (GCA). Although exhaustively tested, neither of these two radar techniques seems to have been very acceptable operationally, because of the limitations of the reflective signal (noisy), traffic capacity (one GSN-5 radar per aircraft), or overall complexity of signal processing and data linking transmission to the aircraft in a high quality format.

Also, during and after World War II, the development of fixed-beam microwave systems (2600 Mc and 5000 Mc) was pursued by Sperry and the Air Force. The microwave ILS was a basic improvement on the SCS-51 system. Beams were better controlled, greatly improving course quality and flyability. The direct,

on-board processing of an ILS type signal overcame the radar limitations of ground and weather clutter, target identity (control signals correlated with the right aircraft), traffic capacity, etc. The signals are in analog format suitable for activation of many types of cockpit displays, the autopilot, and any combination of the two (for full automatic, split-axis, or full-manned flight). Microwave ILS signals are "broadcast," so that as many aircraft as practicable can receive the signals. Each receiving aircraft is assured that the guidance signals represent its location and direction to the landing strip.

With direct transmission, the signal is 60 to 100 db higher than a radar reflective signal, so that simpler lower-cost equipments, not needing extensive signal processing, can be applied. Although voice-guided GCA is often considered valuable, it is in practice, limited by available communications channels, and the additive delay of ground controller and pilot reaction times (often amounting to many seconds). This delay is undesirable for low visibility guidance and good flight control. A fraction of a second delay for direct beam type systems is typical. From the viewpoint of high quality, qualitative, reliable, flight control data, the ILS type systems (and particularly the microwave ones) are far superior. For backup, emergency, and limited applications, radar-only systems have some application, but do not now qualify (after the past twenty years of development) for the prime job of tactical landing guidance in low or marginal visibility conditions. Most radar techniques require bulky equipments, primarily because of the low signal reflected from the aircraft (requiring extreme powers and antenna gains in the ground transmitter, and for the signal processing to minimize noise, ground reflections, and weather. Thus, the microwave ILS type concepts afford a much lighter weight, higher performance, simpler, and far more economical approach to this problem. For example, a microwave ILS ground station with an average power level of 20 to 30 db (100 to 1000 times less than that of a radar) will weigh perhaps 10 percent, of that of an equivalent radar system (10 to 20 miles). This is evident since one-way free-space attenuation to 10 miles is over 130 db. Furthermore, the costs, including equipment, personnel, and installation, may approximate the same (5 to 1 or 10 to 1) ratio. Also, the safety and reliability can be higher (particularly for microwaves) for the ILS type systems where signal directivity provides higher course quality and consistency than the early SCS-51 (and even some of its latter versions).

1. BEAMS AND PATH QUALITY

Thus, we are at the point of specifically asking what determines the nature of the guidance signal and its effect on the aircraft displays and flight control equipment. Detailing the faults of the SCS-51 is probably a good starting point. With only a five-loop array, the so-called "beams" were in reality two large, overlapping, kidney-shaped, radiation patterns with a slope near the cross-over that was in terms of db/degree very low. This is illustrated in Figure 17, which shows the radiation patterns of the SCS-51 and the rectangular representation of the beam slope at the cross-over (course centerline 0). This will be used for comparison to other systems with improved course quality. Although the five-loop array fitted on top of a K-53 truck and was considered even at the time of World War II as air transportable (with a trailer for the glide path), the reliability and siting problems resulted in the ILS concepts receiving much criticism. Course bends, flat spots, lack of clearance signals, course instability (with time or weather) were typical SCS-51 complaints. Most of this was attributable to the low beam slopes of the course and the fact that much of the energy was radiated elsewhere where it reflected from trees, power lines, hangars, hills, etc., to return into the course sector, causing the difficulties enumerated above.

After the war, much effort was placed on correcting this problem, and the localizer is the best example to follow. The WADC C and N Laboratory tried large wire, parabolic reflectors to direct the energy down the landing strip, and this was successful to a degree. Competitive techniques of an array of linear dipoles, and slotted waveguides resulted in the CAA (now FAA) installing the directive arrays using waveguides about 90 to 100 feet long and an eight-loop array for clearance signals (and side-lobe suppression). This clearance array development, its nature, and why it is essential to obtaining safe, clean beams is important to review. Figure 18 illustrates the meter action from a clean symmetrical beam. The ratios of differences, after being normalized, are typical of the relationship between two overlapped beam signals at angles off course.

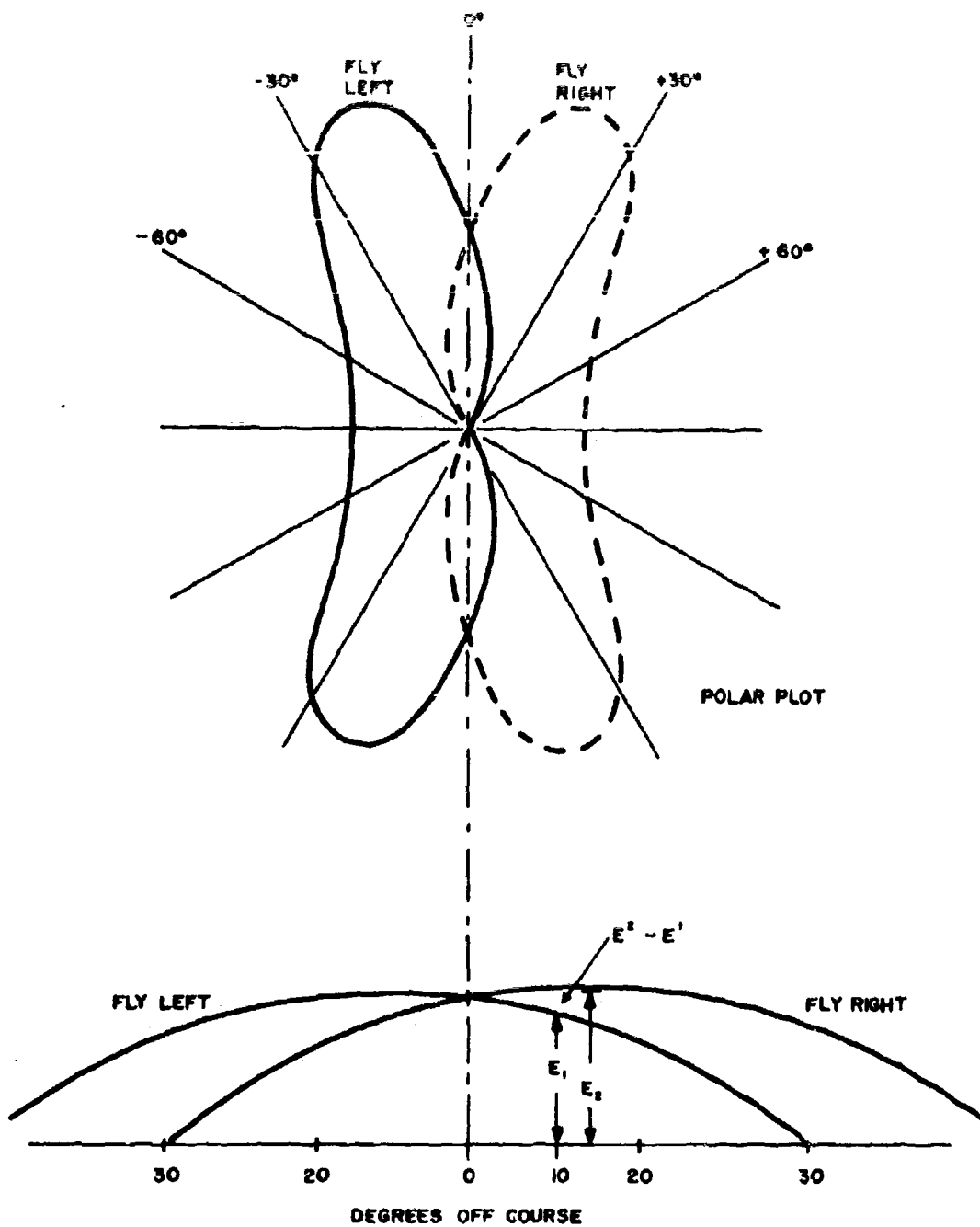


FIGURE 17 SCS-51 PATTERN OF LOCALIZER BEAMS

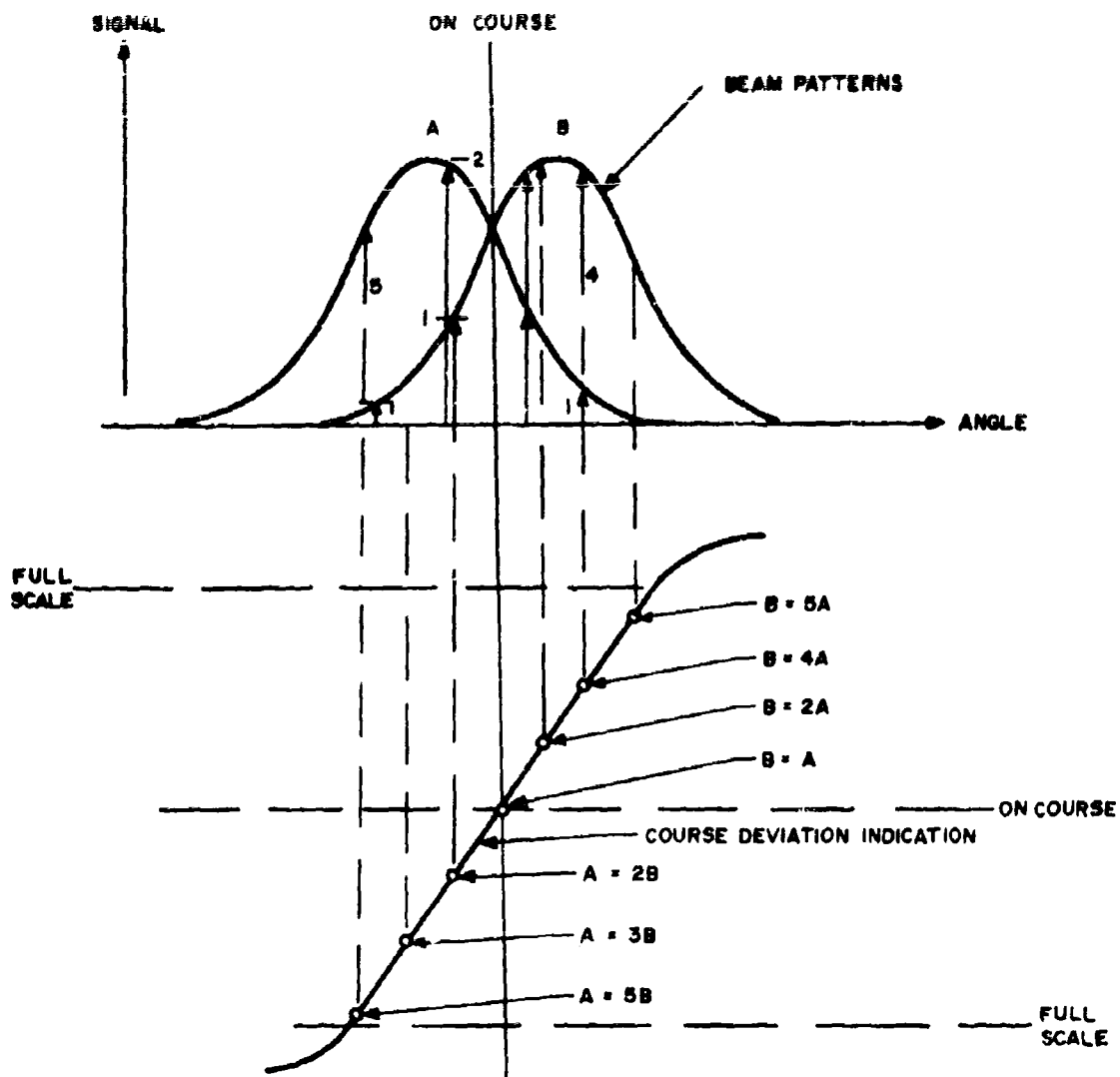


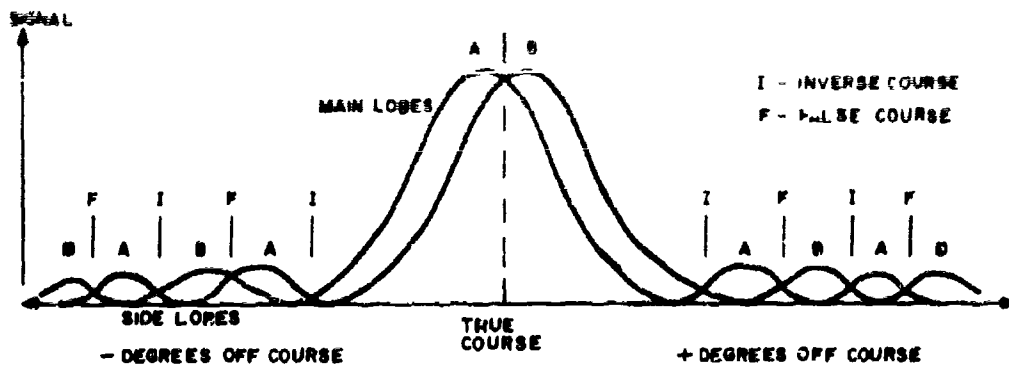
FIGURE 18. TYPICAL GENERATION OF A DEVIATION INDICATOR CURVE FROM BEAM RADIATION PATTERNS

2. THE DILEMMA OF DIRECTIVITY, FALSE COURSES, AND COURSE QUALITY

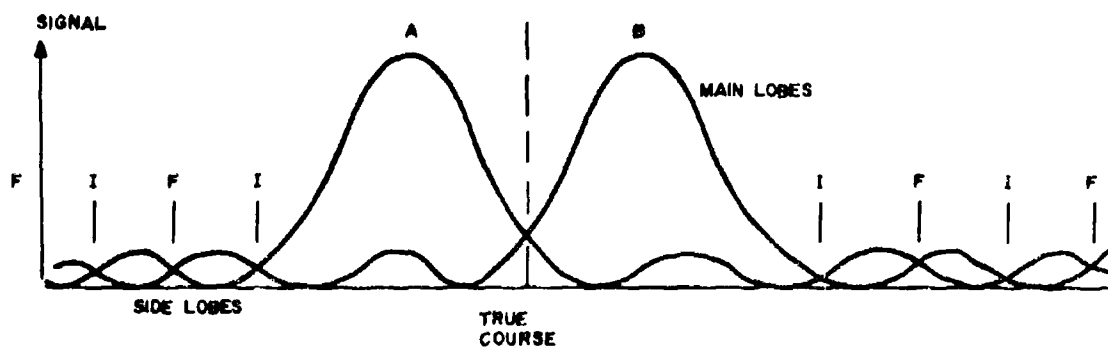
It is desirable to obtain high course quality (linear deviation, cross-over, stability, etc.) so that the airborne display or other utilization of the signal can be based on a rather simple assumption: that a straight line emanating from the centerline of the runway exists with straight-line, linear deviation signals on both sides. To meet this criteria it became necessary to have sharper beams. The beams were effectively reduced from very broad beams to beams about 8 to 10 degrees wide (measured at the half-power point). By overlapping the beams (see Figure 19), the desired course is established. However, in doing this, the side lobes of the narrow beams, even though down in signal by as much as 20 db, would create false and inverse courses near the true course. Since the dynamic range of a one-way transmission system for landing is about 140 db, the sensitive receivers would treat the false courses or inverse course in the same manner as the desired true course. Most systems have signal-to-noise ratios of better than 20 db, even at extended ranges. This creates serious problems of safety, and it is doubtful whether means are available to assure the pilot that he was always on the true course, since the false courses could be perhaps only 10 to 20 degrees removed. Figure 20 illustrates the receiver action.

This resulted in the WADC C and N Laboratory, CAA, and others retaining the broad beams of the now eight-loop array (five was completely inadequate) and utilizing them to "swamp" or "suppress" the side lobes of the directive radiation. The currently commissioned waveguide localizer that is considered, perhaps, the best available ICAO facility (that is widely installed) utilizes essentially two completely separate transmission systems, both operating within the band pass of the localizer receiver. The so called "AM capture" effect essentially allows the airborne receiver to be activated by the narrow precise beams without undue influence of the wider clearance beams that cover nearly 360 degrees. This is a complex installation of two, dual transmitters, dual monitoring, and dual antennas (eight loops and the waveguide are separated physically to get independent radiation patterns). Figure 21 illustrates this pattern.

This has been created for fixed ICAO ILS installations, a facility that in most cases has few course bends, and is stable with linear deviation signals. There is a debate currently under way relative to the maximum acceptance angle without false or inverse courses. Some agreement may be reached at a figure of 35 degrees of the true course rather than 180 degrees. This may permit special, tapered patterns to suffice, rather than independent clearance patterns. However, in all cases (USAF MRN 7-8, V-Ring, UK dipole array), the aperture and physical sizes



TWO BEAMS AT HIGH CROSS-OVER



TWO BEAMS WITH LOW CROSS-OVER

NOT TO SCALE

FIGURE 19. FALSE COURSES ASSOCIATED WITH NARROW BEAMS

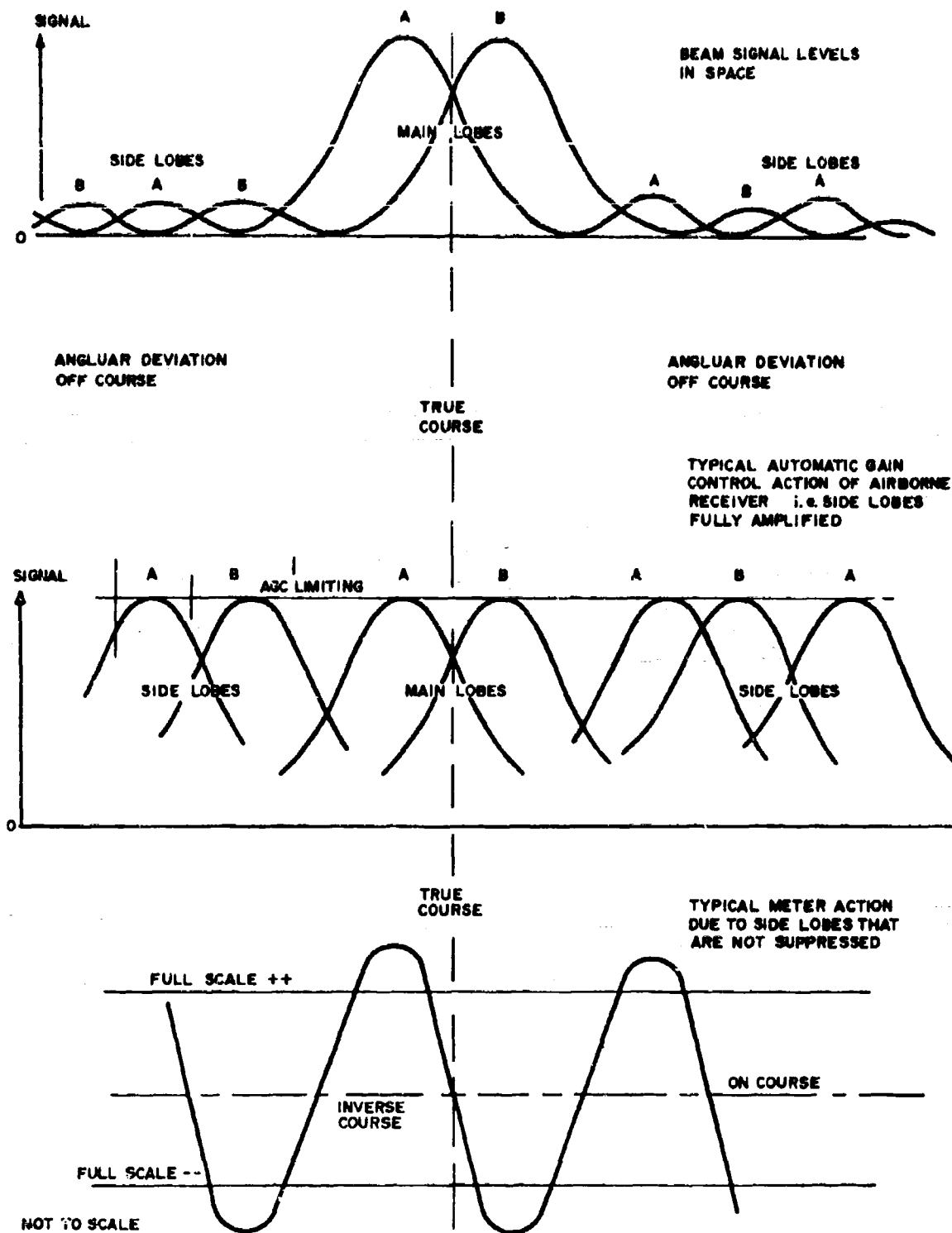


FIGURE 20. AGC ACTION

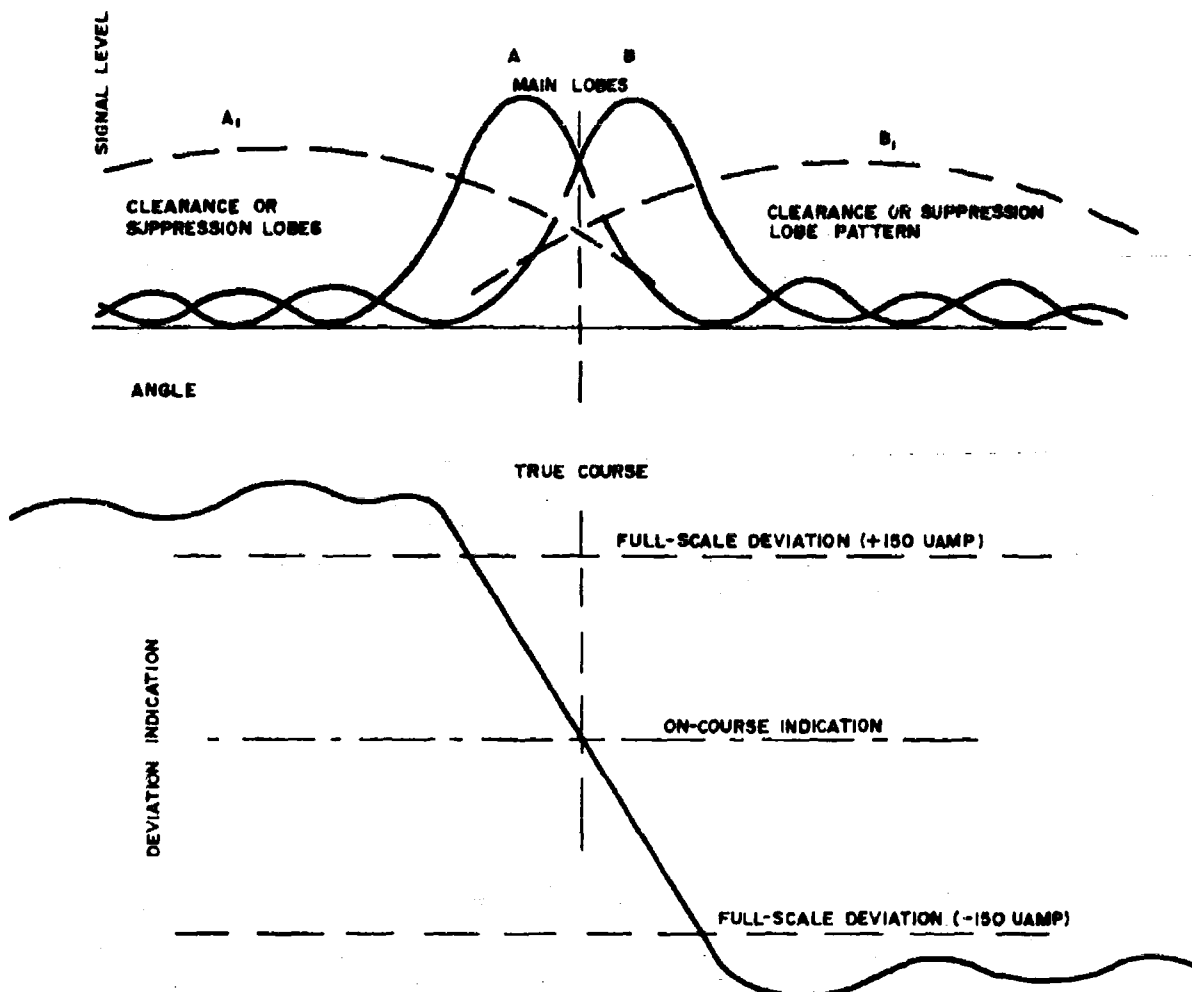


FIGURE 21. USE OF SIDE-LOBE SUPPRESSION OR CLEARANCE SIGNALS TO ELIMINATE FALSE AND INVERSE COURSES

are well beyond the requirements of a truly portable, quick set-up system. Sometimes months will be involved in installation, flight testing, and modifications to achieve the desired course quality for CAT I or II. The ILS glide slope is another very serious problem that will be discussed separately.

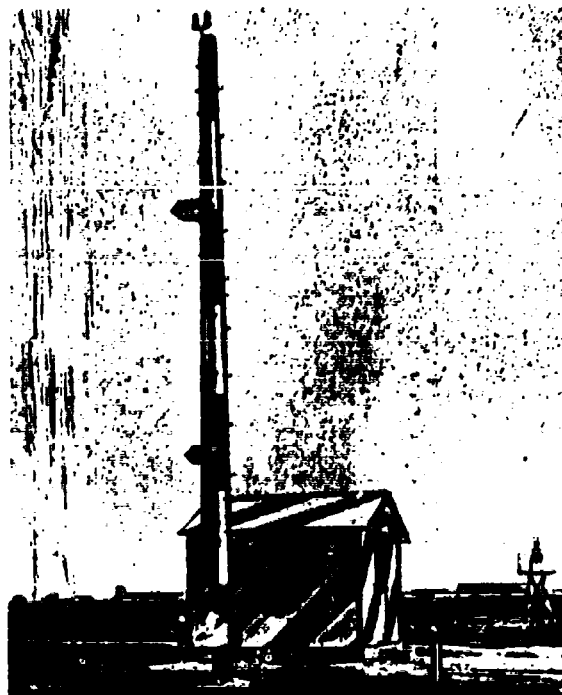
Essentially, the ICAO ILS concepts are acceptable for large permanent installations. The USAF, of course, has these as well as the FAA for such operations as ADC, SAC, and MAC, so that there will be a continuing Air Force interest and usage of the ICAO ILS for many years. But it will not meet the tactical requirements of light weight, small size, quick set-up, and good quality. Such a system is required in battle areas and in overseas military theaters.

If one examines the same system at a frequency of, say, 2600 Mc (where one was built for the USAF All Weather Flying Division), the same course qualities are obtainable with antennas only a tenth or twentieth of the size. Furthermore, since this development (20 years ago), the technology has provided just as reliable transmitters, receivers, frequency stability, antennas, etc., in this region as in the 110 Mc region, so that pioneering in any of the potential microwave landing bands is no longer required. S-, C-, K-, and X-bands are fully developed microwave bands, some having been applied previously to the landing problem. Thus, it is evident that a tactical counterpart of the ICAO ILS type system will be in the microwave spectrum for reducing size, weight, and to achieve improved performance in difficult sitings of landing strips.

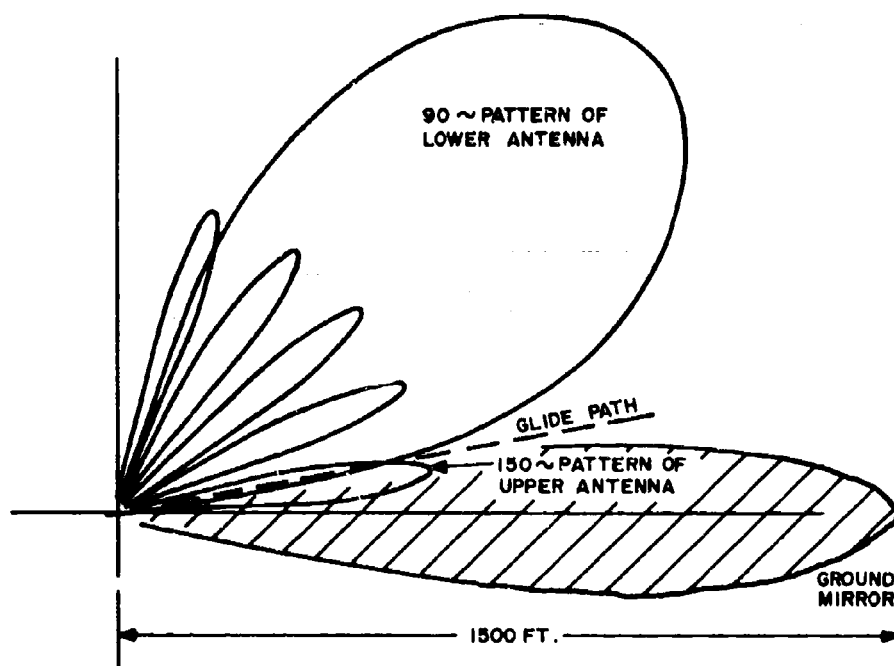
3. THE DILEMMA OF VERTICAL GUIDANCE

Similarly, the problems of vertical guidance started with the first military landing systems: SCS-51 and the GCA. Figure 22 illustrates the basic principles of the ICAO reflective glide slope. The bottom dipole placed a given height above the reflective surface of the airport creates a set of vertical lobes, whereas the second dipole, which is placed higher, produces another set of vertical lobes. The bottom lobe of the upper antenna serves as the upper beam. The "null-reference," M-arrays, etc., change this description somewhat, but they all have in common the need for a large surface in front of the antenna toward the approach area that is virtually flat (for 1500 to 2000 feet).

Irregular terrain results in irregular beams. Since most airports are graded smooth for the flat runways, the shoulders (say 300 to 400 feet off centerline) often provide a flat surface.



TYPICAL STANDARD GLIDE PATH



BASIC GLIDE PATH RADIATION PATTERN

FIGURE 22. TYPICAL STANDARD GLIDE PATH AND BASIC GLIDE PATH RADIATION PATTERN

This requires the origin (the antenna itself) to be located some distance from threshold to obtain the 1500 to 2000 feet of flat terrain. Some cases have resulted in hundreds of thousands of dollars being spent for fill to obtain this surface. Since threshold areas are irregular and preferably slope downward, this places the approach aiming point far down the runway. For most jets this location is unsatisfactory for ceilings below 300 feet since high vertical velocity, duck-under maneuvers are required to place the aircraft on the runway in the first 1200 feet beyond threshold (see discussions on F-101 and Century-Series Landing measurements).

Over the twenty-five year period since the SCS-51 was developed, the 330-Mc glide slope has gone through about a dozen stages of improvement. This is much like the history of the ILS (ICAO) localizer and with about the same results. Namely, the course quality has been improved, but the antenna is much larger and siting is difficult. The last five years have seen several vertical directive arrays developed that are between 60 and 120 feet high. The directive beams do not depend on the reflective principle, and thus siting is much more flexible so that improved GPIP or ILS reference points can now be established for the jet fighters, bombers, and airlift transports of the Air Force. However, in the tactical theaters where quick set-up is needed, these structures are similarly prohibitive in size, weight, and complexity of installation. The directive glide slopes are being tested by the Air Force and will have applications in many locations fulfilling a need for the permanent base and the compatibility of the ILS through ICAO in about 1000 fixed, permanent airports in various parts of the world. These directive glide slopes, such as the waveguide glide slope (see Figure 23) are flexible in initial siting so that they can be moved forward about 1000 to 2000 feet to increase the IFR useful length of a given runway. They are immune to snow accumulation, taxiing aircraft, etc., to a much greater extent than the reflective glide paths.

Thus, it is likely that for some missions and aircraft the Air Force will continue for some years utilizing this equipment (both air and ground), but simultaneously being much in need of a second, tactical system that will meet in a single "system concept" all the other requirements not fulfilled from the military or tactical viewpoint by the ICAO ILS.

The application of microwaves to the solution of the glide-slope problem was well recognized by the NDRC during World War II and both S-band and X-band landing systems were developed.

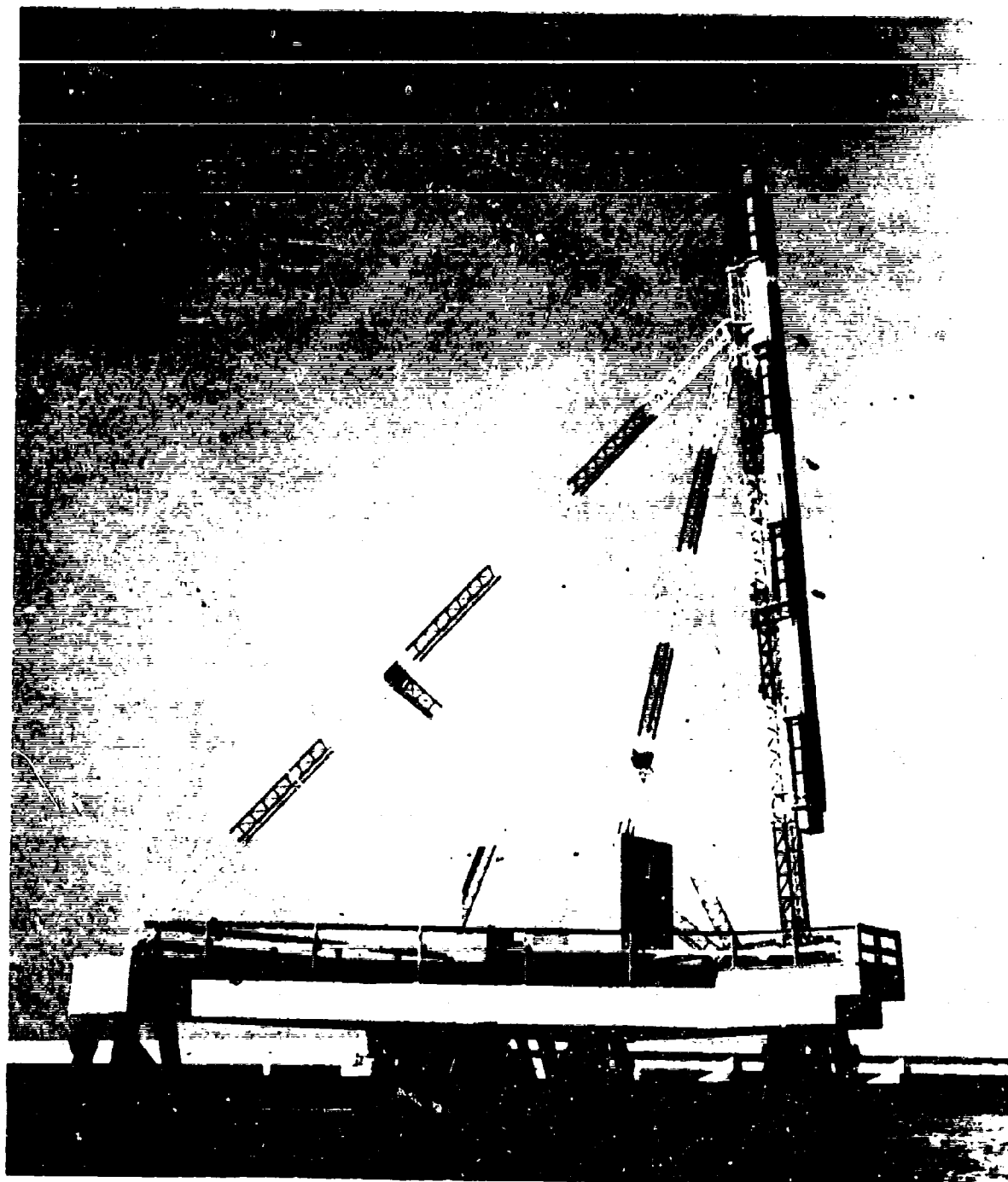


FIGURE 23. WAVEGUIDE GLIDE SLOPE INSTALLED AT LA GUARDIA (RW-22)
AIRPORT, NEW YORK

Later, a C-band system was developed, thus providing experience at three microwave frequencies by 1951. Subsequently, much interest in K_a-band suggests that it is a good compromise for this application. Further details appear in the section on choice of frequency. In brief, this frequency region is not greatly affected by absorption, and it has a clear, international frequency assignment, and it has over seven years of extensive development for this application. Returning to the fundamentals of landing guidance, it will be shown that probably the most critical aspect is creation of good, flexible, vertical guidance signals. The localizer or horizontal radio guidance is also critical, but it will be shown from the viewpoint of a tactical landing system that vertical guidance is the most sensitive of the two. It is further assumed that it is desirable to have both elements of a microwave ILS (type system) on the same frequency so that a common receiver can be used. From this viewpoint the vertical guidance signal becomes the Achilles heel of any landing system development not treated with the greatest of attention from the very inception of the system design.

The undesirability of having the vertical and horizontal guidance systems on separate frequencies--requiring separate airborne receiving units--is evident. Most microwave concepts (several tested) have shown that it is practical to combine by various techniques the two signals without any compromises being made in performance, accuracy, or reliability. In fact, on a total system basis, the performance is improved since the number of units in the aircraft, susceptible to failure, is reduced to half. The common usage of air and ground elements makes inventory, costing, etc., more attractive. DME can often be included in the same units without much further complication, since the usual bandwidths and current technology (microminiaturization and microwaves) allow this; something that is not possible with ICAO ILS. A multiplexed DME on the angular guidance signals avoids three separate frequencies.

4, CREATION OF THE VERTICAL GUIDANCE SIGNALS

For the reasons given in paragraph 3 of this section, it is desirable to let the vertical guidance requirements determine many of the Tactical Landing System's parameters. The localizer and DME will follow suit for the reasons given.

However, as in the case of the narrow-beam localizer previously described, the beam-widths become rather narrow for most glide paths. A beam should be somewhat less in width than the path angle width, (say for 3 or 4 degree) paths, and susceptibility of false and inverse course must be guarded against. It

is also very desirable for many reasons that a side-lobe suppression or "swamping" signal in the vertical plane be avoided, because the vertical plane is not symmetrical relative to a beam as in the azimuth case. The ground reflecting surface is always on one side of the course in the vertical path, which is not the case in the horizontal guidance.

Thus, if one designs a microwave, fixed-beam glide slope for around a 2.5-degree flight path angle, the lower beam that provides the "fly-up" signal (and the proportional deviation) must be narrow enough to adequately minimize the ground reflections. The case of the ICAO reflective glide slope requires and is dependent on the ground reflecting the signal. In the case of poorly designed, directive (antennas), glide slopes (typical of a few microwave systems), ground reflections can be quite deleterious. Vertical re-radiation can create "flat" spots, reversals, non-linear deviation signals, course shifting, etc. Consequently, optical and mechanical settings disagree, and false or inverse courses above the true course (sometimes below) will occur.

This is illustrated in Figure 24. As the vertically crossed beams are lowered toward the ground to establish a lower glide path, increasing amounts of signal are radiated at negative angles into the ground. This signal is reflected or re-radiated. The returning signal deforms the usual symmetrical nature of the beam, as shown in Figure 25.* The course deviation circuits in the aircraft that read the difference of the beams (after AGC normalizing action) do not obtain linear deviation indications in cases II, III, and IV, but these indications can be obtained in case I. It will be noted that as more energy illuminates (or strikes) the ground, even greater deformation of the bottom beam takes place. For example, the beam can have a slope that accelerates, reverses or does not change appreciably over a given angle. These perturbations create reversals, flat spots, nonlinearity, and shifts of the course. Figure 26 is a point-by-point illustration of this phenomenon. If a flat spot occurs at the desired course, this is quite devastating for the airborne displays, path computers, or flight controls, since the deviation signal remains constant, though the aircraft is actually changing in vertical angle, as shown in Figure 27. The flat spot can occur readily beneath the cross-over (or course indication), with the result that the flight instruments cannot safely use rate-of-closure to the path since the displacement is not linear

* See section 2.2 (particularly pages 36 and 39) of Propagation of Short Radio Waves; Vol. 13, Radiation Laboratory Series, for a more complete discussion of this important point.

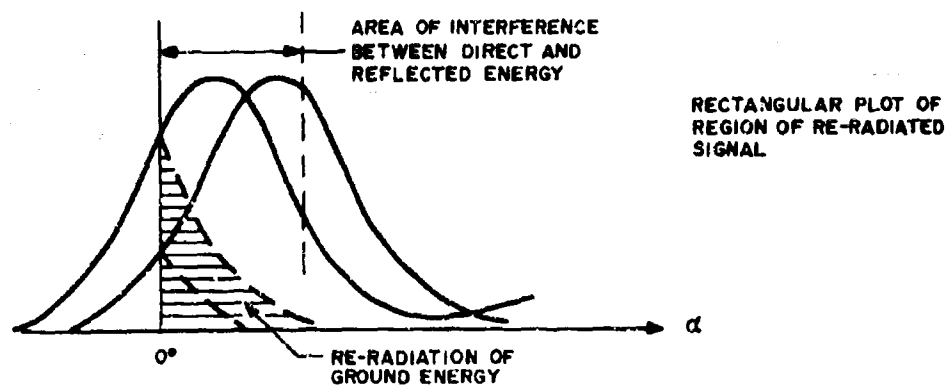
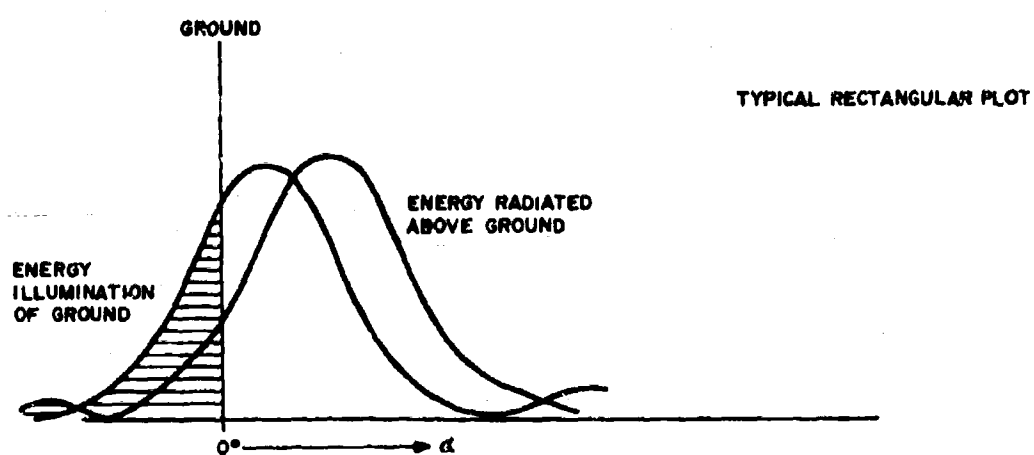
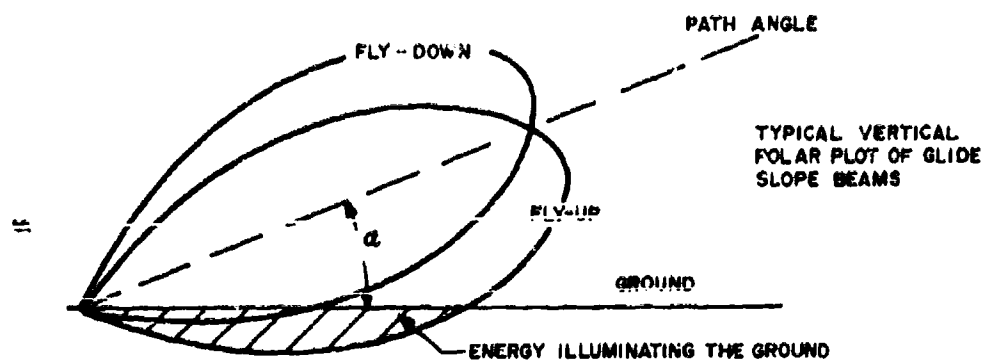


FIGURE 24. VERTICAL BEAMS REFLECTING FROM GROUND

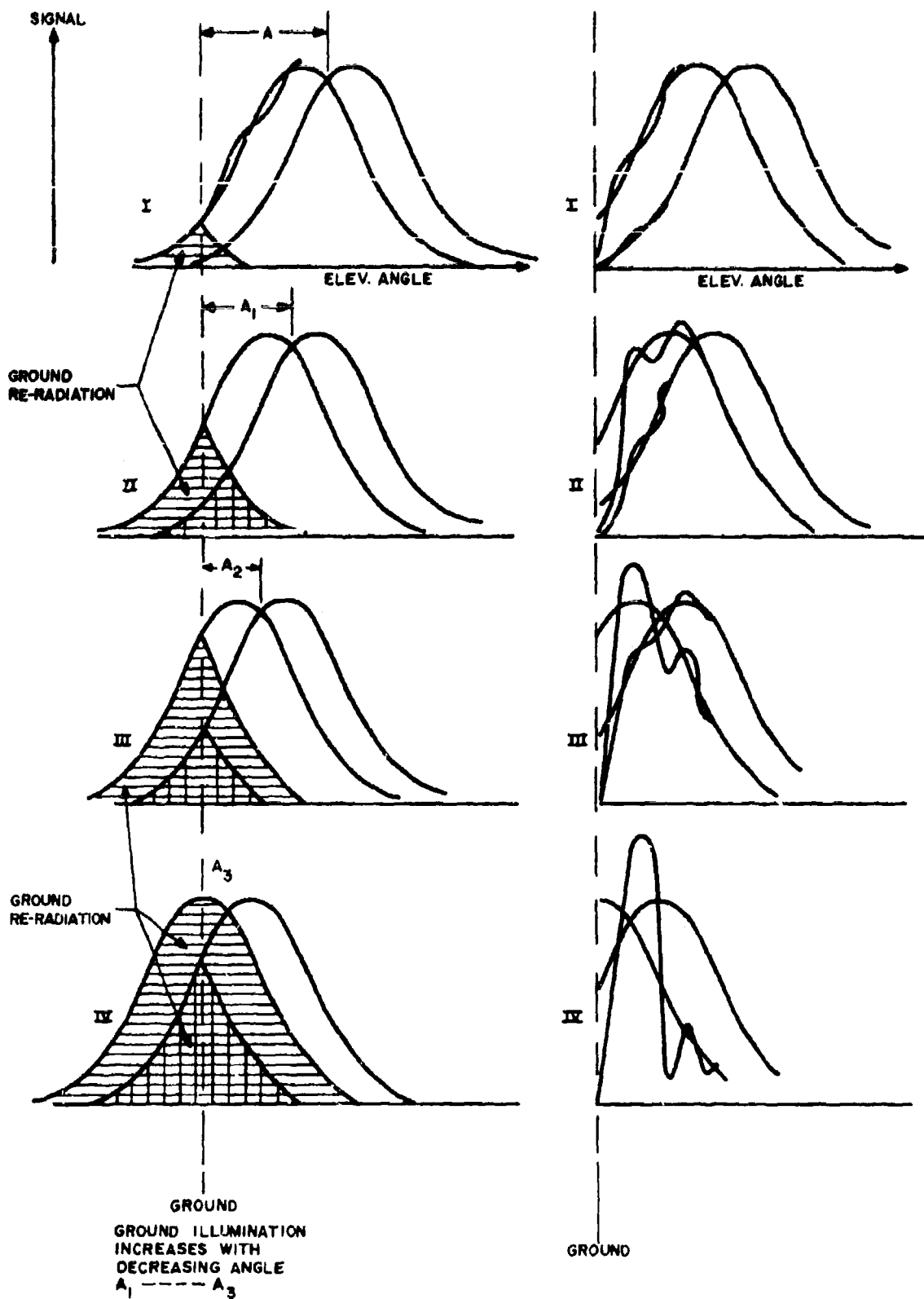
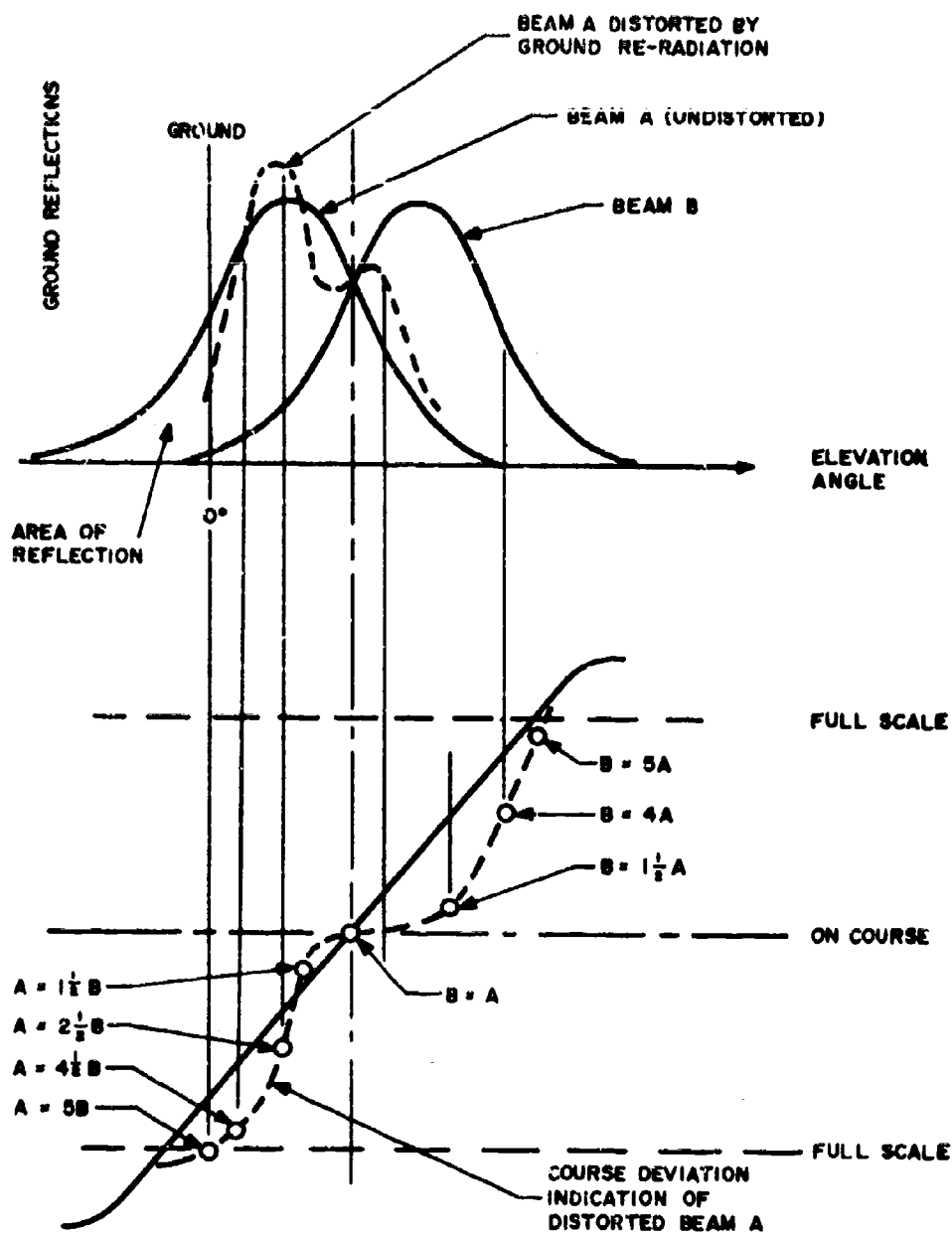


FIGURE 25. TYPICAL BEAM DEFORMATIONS DUE TO RE-RADIATED SIGNALS
ADDING AND SUBTRACTING TO OR FROM DIRECT SIGNALS



NOTE:

FIGURES 26 THROUGH 29 PRESENT CONTINUING
EXAMPLES OF THE DISTORTION OF LINEAR
METER ACTION

FIGURE 26. BEAM DISTORTION BY GROUND RE-RADIATED SIGNALS AND THEIR
EFFECTS ON COURSE DEVIATION INDICATOR

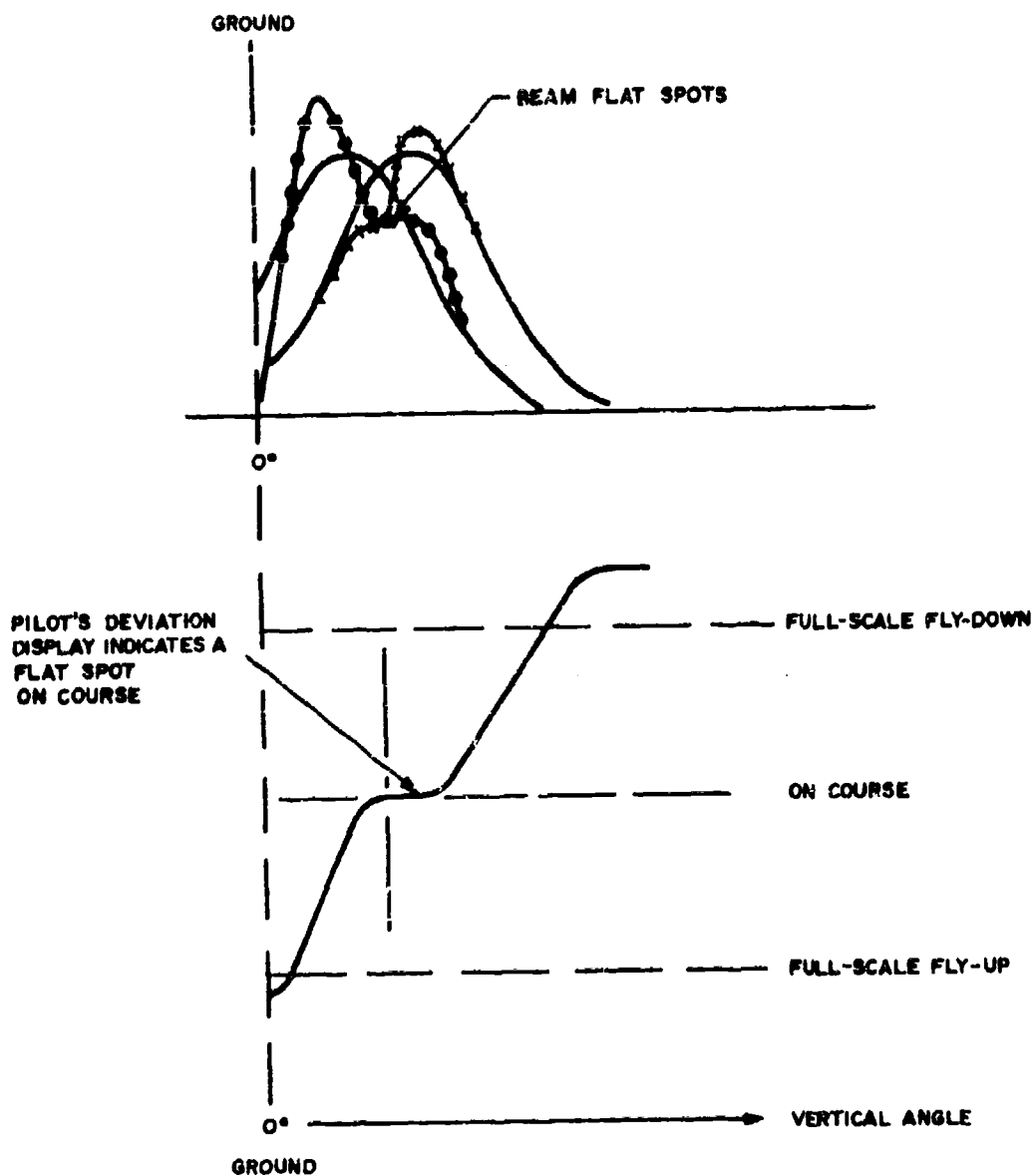


FIGURE 27. BEAM PERTURBATIONS CREATING FLAT SPOT ON COURSE DEVIATION INDICATOR AT ON-COURSE POSITION

(Figure 28). In some cases, if carried to the extreme say a vertical path angle generated by beams twice the width of the vertical path angle (at the 3-db points), the deviation indication can reverse itself as the aircraft approaches the course (Figure 29). This course reversal situation causes the aircraft controls, if automatic, to reverse sensing in this flight path region of the deviation signal coverage. Or, if the pilot is flying the course with a display, it causes him to fly away rather than toward the desired course.

Other limitations occur as the beam is elevated for higher approach angles than is the case for a typical ILS of 2.5, 3.0, or 3.5 degrees, such as is probably quite typical of a tactical landing. In a minimum prepared, forward strip, where the clearance criteria are not the usual 1/50, but might be only 1/25 (or 1/10 for a helicopter), higher angles are needed. In this case the path angle might be elevated to, say, 6 degrees or even 10 degrees. Since the narrow beam is now elevated, it has the possibility of a false course appearing beneath the beam (Figure 30). Certainly, for helicopter cases where the 1/10 obstacle line is such as to require a course (glide-path) at about 9 degrees (since the obstacles are at 6 degrees), to allow for a reasonable deviation signal and clearance below the path, the false course of the narrow 2 to 3 degree beams will be evident and an extreme hazard.

Thus, one concludes that in the case of heavy, fixed-wing aircraft and civil applications, the normal 2.5 degree and 3.0 degree cases could be satisfied by a set of microwave fixed beams, and this is also true of some tactical cases. However, where reasonable tactical flexibility of glide path is desired, either flat spots, nonlinearity, reversals or false courses, may be generated. To limit the tactical system rigidly to an ICAO limit of only 2.5 to 4.0 degrees does not seem reasonable with STOL, helicopter, COIN, V-STOL, and other aircraft that are more typical of a tactical aircraft (than the heavy fixed-wing jets) capable of flexible landing sites.

One cannot limit the site selection of forward strips to standards equivalent to a class A ICAO airport. Clearance criteria must be relaxed to provide the field or theater commander maximum flexibility in the choice of airport or the location of his landing strips. By relaxing the clearance (obstacle line) criteria, the associated descent path to safely clear the obstacle line will be higher. With approach aiming points nearer the thresholds (than with the ICAO ILS), it is likely

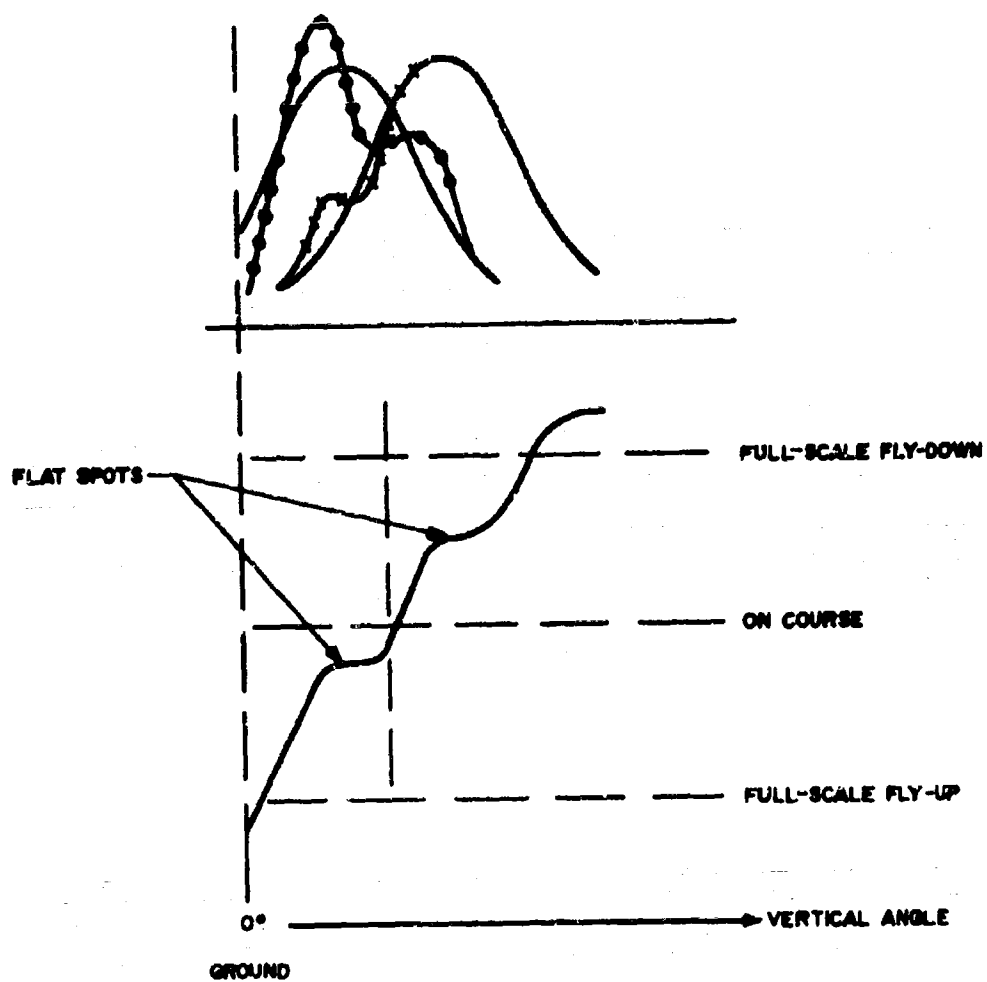


FIGURE 28. FLAT SPOTS ON EITHER SIDE OF ON-COURSE

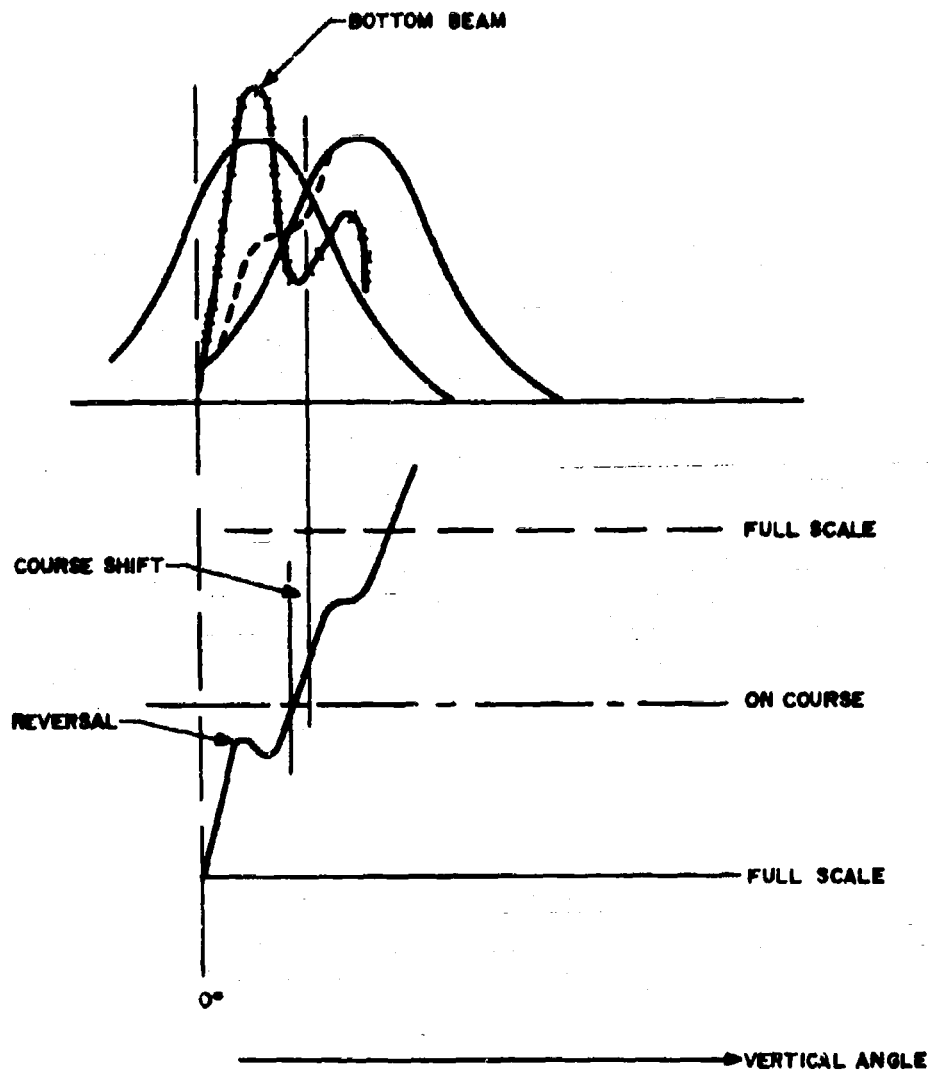


FIGURE 29. TYPICAL COURSE SHIFT (FROM OFFICIAL) AND METER REVERSAL CAUSED BY VERTICAL BEAM DISTORTION

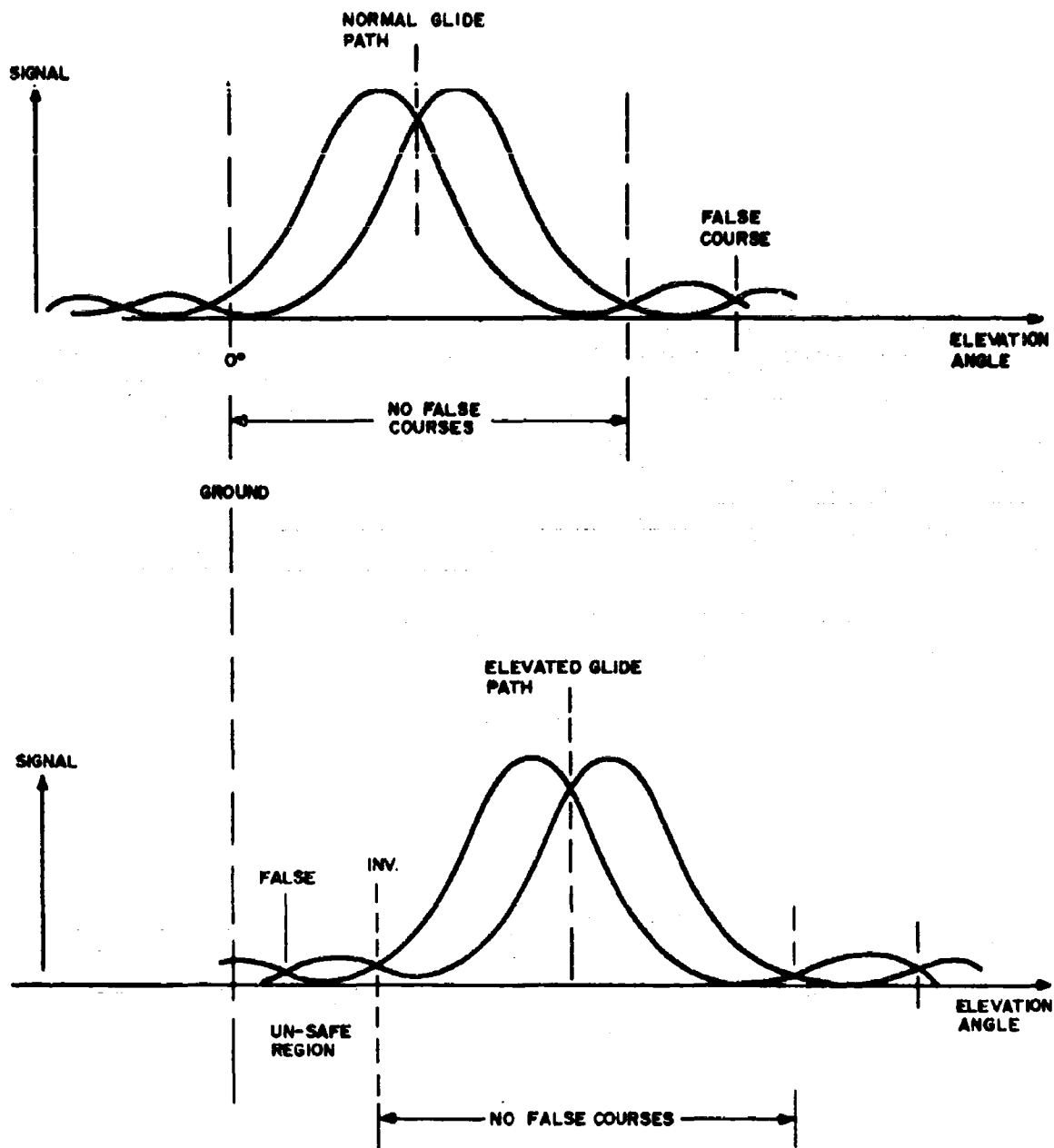


FIGURE 30. DANGER OF FALSE COURSES BELOW ELEVATED GUIDE PATH

that many of the fighters and even jet transports can fly well at steep angles of around 6 degrees. The higher sink rates and increased vertical energy must be taken into account, but the flare is started higher and further out (well above obstacle lines), so that the strip length is effectively used even with steeper angles. Boundary layer control, blown flaps, and many other aeronautical tests for achieving tactical steep angles for approach in a battle area, strongly suggest that this type of flight path will be achieved. Similarly, in studies of the "duck-under" maneuver, it is noted that many jet fighters, bombers, and transports already use much steeper angles for visual and "duck-under" landing maneuvers, so that many current aircraft could be flown tactically in this manner. In fact, the WADC, NASA (reference 59), and FAA efforts in the steep approach field suggest that it is feasible if the vertical guidance is adequate.

Thus, in the trade-offs of a tactical landing system development, the environment of minimum strips with poor clearances must be given priority in the conceptual consideration of the vertical guidance signals rather than the ICAO concepts for large civil fields. This has not been introduced into Air Force planning as yet, but will be when adequate guidance and control is available. Thus, this tactically desirable glide slope should specify not only the usual angles (down to 2 degrees), but also angles as high as may be required for a minimum prepared strip where the battle situation does not permit many choices of locations and where poor obstacle lines exist. This would suggest that paths as high as 6 degrees (perhaps 15 to 20 for helicopters, STOL, and/or COIN aircraft) be considered. The operationally desirable situation would preferably utilize the same equipments without the need for making adjustments of the air or ground units.

For fixed beams, this can be achieved by using different antennas that have different beamwidths. As illustrated in Figure 31, if this approach is taken, the beamwidth in the vertical plane could be varied so that it is approximately equivalent to the glide angle (at about the 6-db points). Note the beam change from shallow to steep paths that is required. Otherwise the false courses or reversals, flat-spots, etc., are encountered if a given fixed beam is used.

Figure 31 illustrates the path at different vertical angles using different beamwidths. With four different beams this may be possible. A four-sided box with four different antennas, one on each surface, can be arranged so that one side

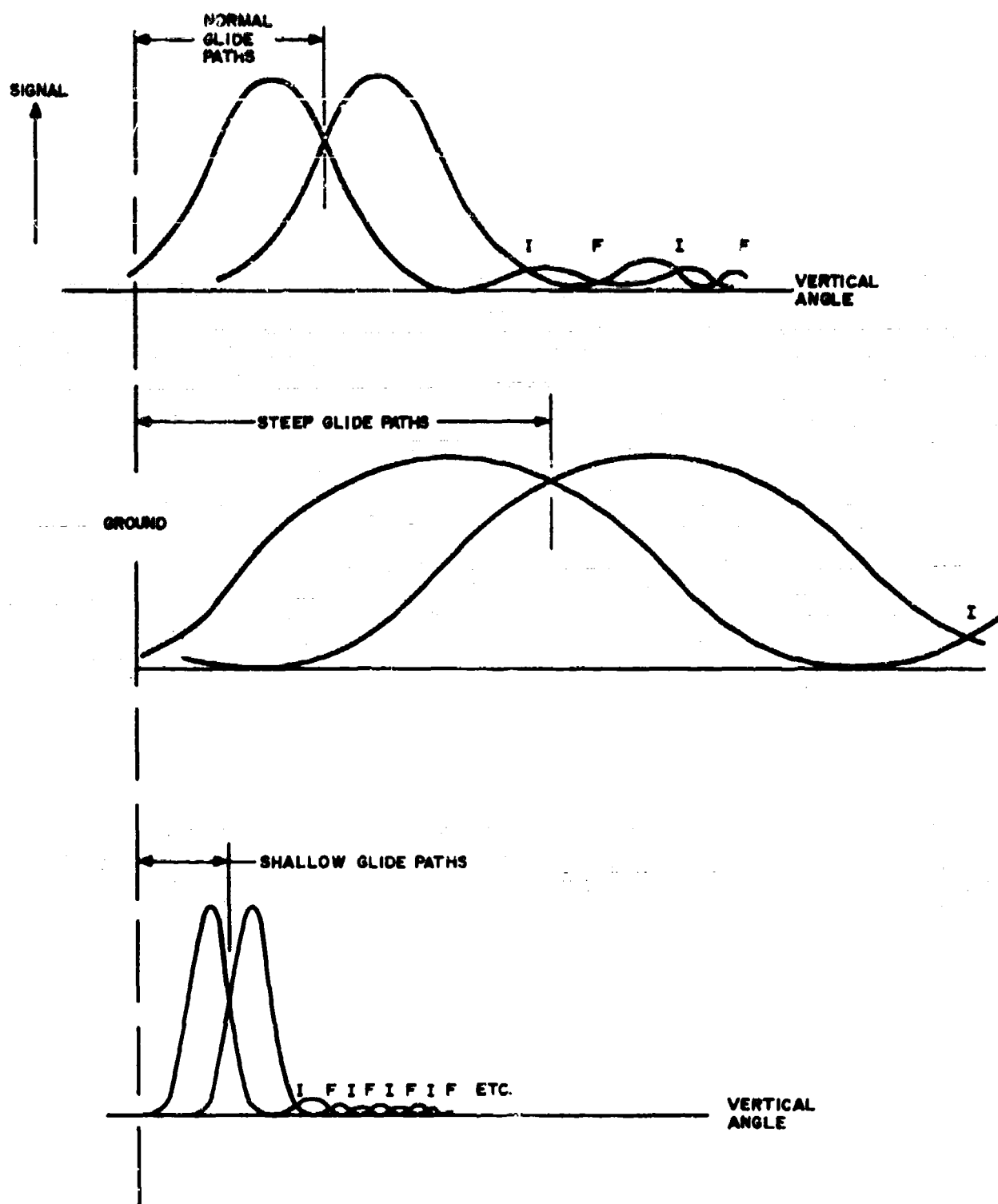


FIGURE 31. BEAMWIDTH VARIATION WITH VERTICAL PATH

is selected and a switch connects the transmitter to the selected antenna. Nonsymmetrical beams and combinations of wide and narrow beams are often used. In such cases careful control of the signal levels of each beam is required. A wider beam spreads the energy so that its maximum signal will not equal that of a narrow beam, assuming a common source of radiated power.

5. SCANNING BEAMS

Some virtues of scanning beams, not achievable with fixed beams, are evident. The scanning beam can be made narrow and scanned over several beamwidths (10 to 40 times is typical; see references 29 and 31). As the beam scans, the AGC of the airborne receiver limits the reception of the beam processing (demodulation circuits) to only the upper 6 db or so of the beam. This effectively suppresses the side lobes. Furthermore, the beams can be made narrow to handle the minimum shallow path anticipated (often needed as flare guidance for high-performance, tactical jet aircraft). The same beam can provide steep or normal angle guidance. These basic characteristics are illustrated in Figure 32. More details on fixed and scanning beams appear in Section VII of this report.

6. BEAM CROSS-OVER POINTS

Another variation on course widths is obtained by varying the cross-over point of two similar beams. This is illustrated in Figure 33 where two typical cross-over points are shown. In one case the cross-over may be 2 to 3 db down from the beam nose while in the other ("low") case it might be 6 to 7 db down from the beam nose. The rate of change of beam "differential" signal will be seen to be greater for the lower cross-over. (See Figure 18.) In fact, one limiting case is the coincidence of the two beams where the slope differentials are zero. The other limit is where the beams are so far apart as to have a very limited linear region and adjacent side-lobe cross-overs. Although the low cross-over (separated) case indicates a greater apparent db/degree change, its total linear dimensions are less. It is less susceptible in some respects to ground reflections, because of this greater change. However, it should be noted that for a given beamwidth and vertical path angle, the lower beam is depressed, resulting in more ground illumination.

In the case of the high signal cross-over, the course width is greater, but the db/degree change is less and thus more susceptible to ground reflections that distort the beams

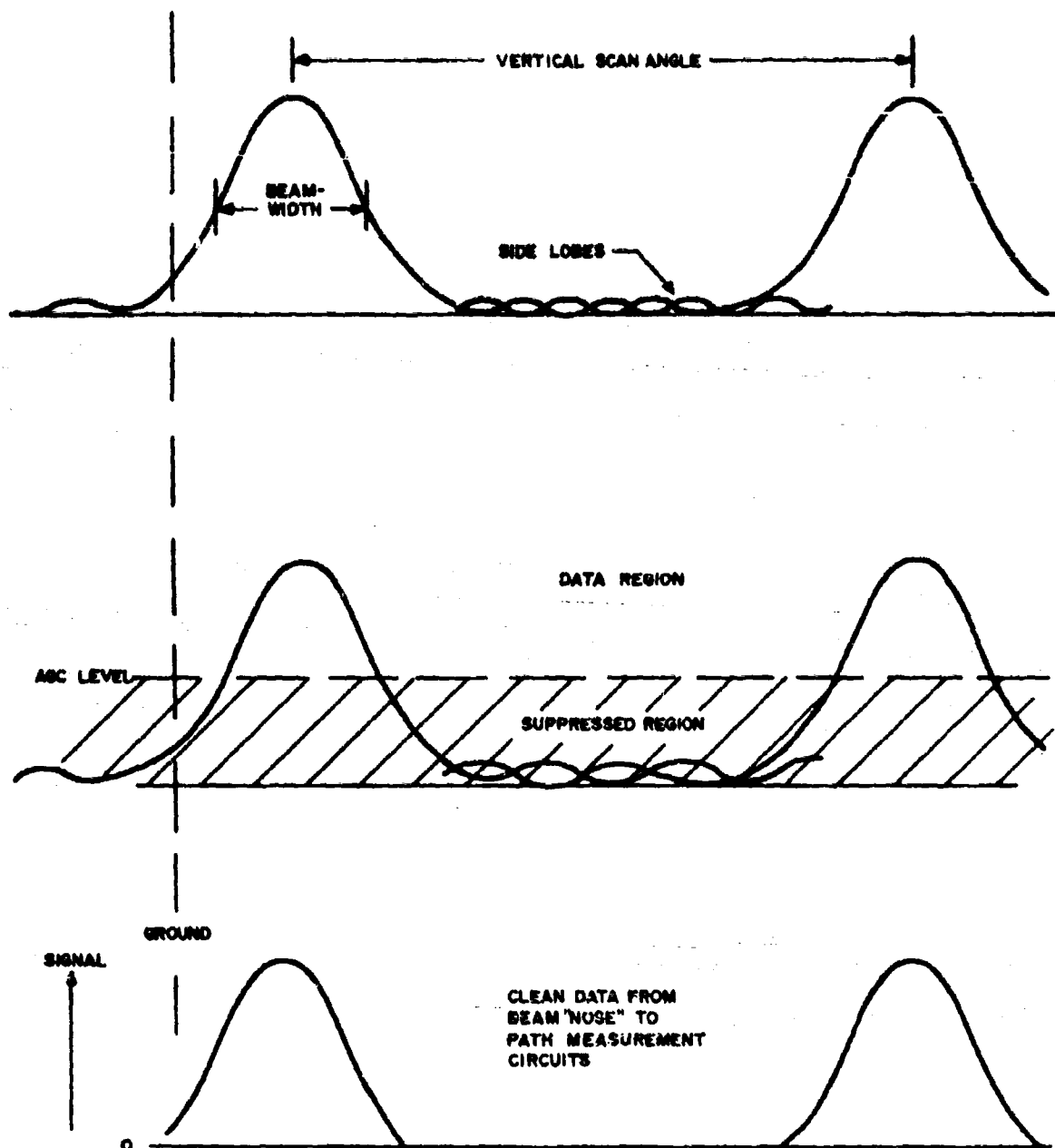


FIGURE 32. SIDE-LOBE SUPPRESSION IN SCANNING BEAMS

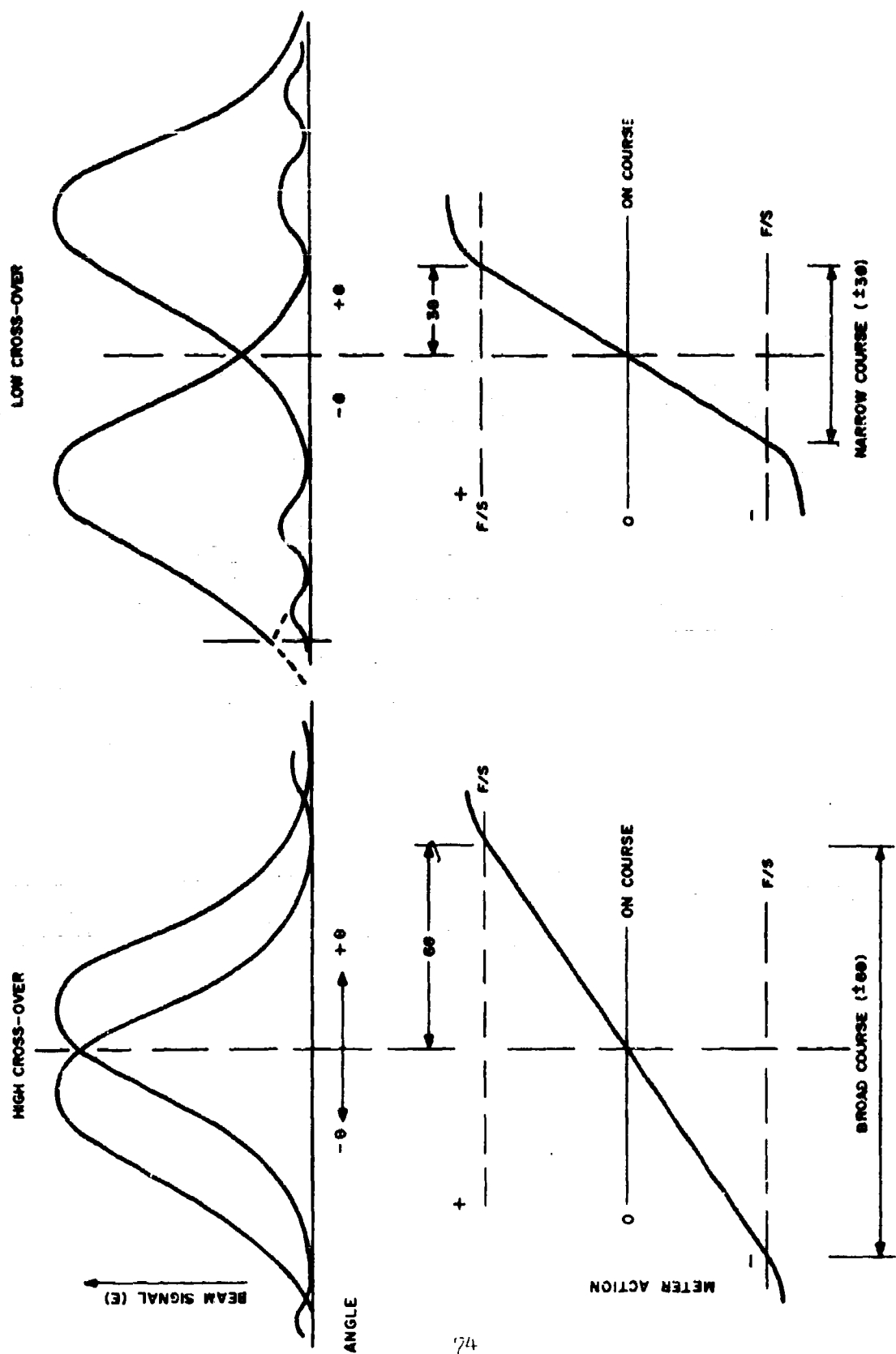


FIGURE 33. RELATIONSHIP OF COURSE SENSITIVITY TO BEAM CROSSOVER POINT

and course deviation indication. This is illustrated in Figure 34. From a design viewpoint this (cross-over point) variable has limited application. With careful planning and field siting, it is possible to obtain about a two to one variation in course width. This might be useful in horizontal guidance, but can be treacherous in the vertical plane because of the ground reflection affects previously noted. Figure 35 summarizes certain "meter-action" or deviation indicator terms.

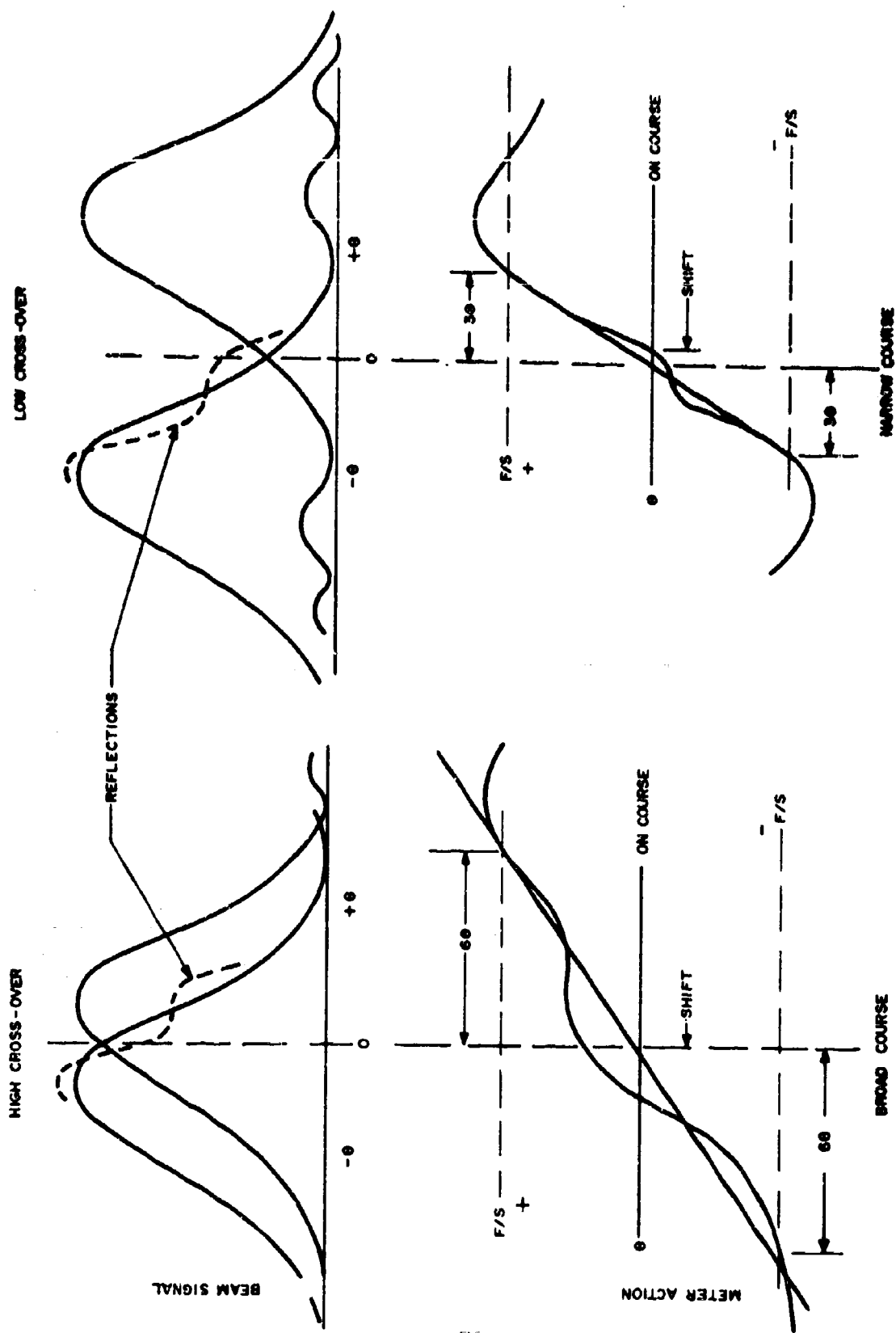


FIGURE 34. RELATIONSHIP OF COURSE LINEARITY TO BEAM DISTORTION

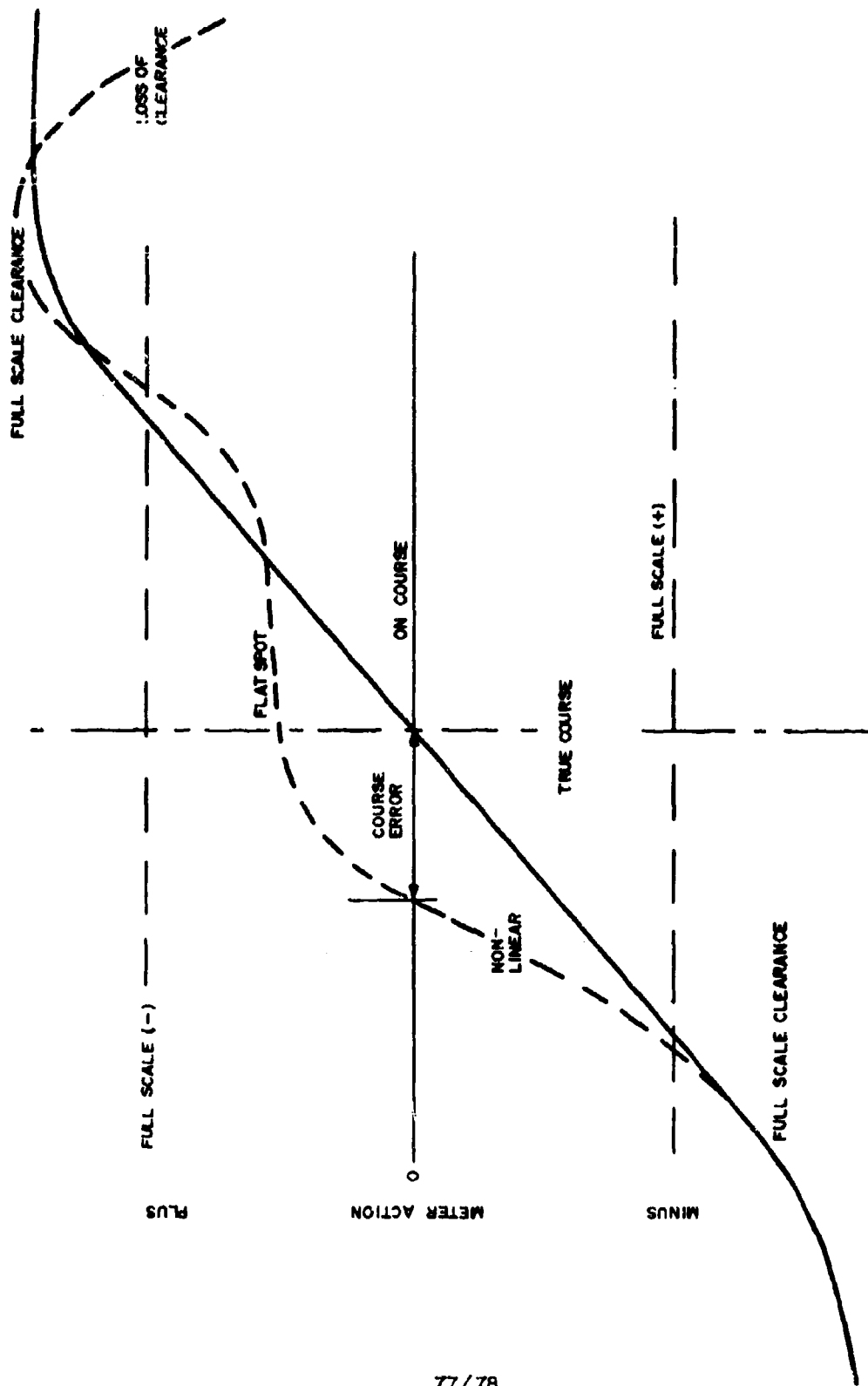


FIGURE 35. DEFINITIONS OF COURSE DEVIATION INDICATOR RESPONSE

SECTION IV

OTHER RELATED GUIDANCE TECHNIQUES

It is not likely that a fully self-contained means of low visibility landing guidance will be available for a decade or more. No current technique seems suitable for establishing IFR landing accuracies of a few feet at the end of typical tactical missions. Current inertial systems that are likely to be carried by tactical aircraft have drift rates measured in thousands of ft/hr (references 54 and 55). Low-cost units (still around 50 thousand dollars) will have positional drift rates of about a mile/hour. Even with updating from other sources that might reduce the errors, it is very unlikely that the precision needed for low visibility localizer signals could be obtained (10 to 20 feet at runway threshold), because a tactical area does not have precise coordinate data nor precision area guidance.

The vertical guidance signals from inertial, low-frequency navigation or other similar self-contained systems (not requiring a cooperative unit at the landing strip), could not meet the precision of the glide-path signals by probably two orders of magnitude. DME and radio or barometric altimeters have been tested. However, if a DME is desired, it should be a modern, precise one, and multiplexed with a glide slope.

An examination of typical airborne radars that would be found in tactical aircraft indicates that, used without any surface aids (beacons or corner reflectors), they are also not very promising as a landing aid. The display, scan rates, need for integration of other data, and basic limitations of primary radar, make this an uninviting approach. The weather (rain, snow, etc.) and complex ground return signals (clutter) make the radar scope presentation very unsatisfactory when compared with a typical flight director for low-visibility instrumentation. Most radars have beamwidths of a few degrees, making the resolution of the strip at a reasonable distance for alignment nearly impossible. A 100-foot wide strip, viewed from 5 miles, subtends an angle of only 0.25 degree or only about 5 to 10 percent of a typical beamwidth. Special radar techniques, such as interferometers, beacons, rotating corner reflectors, etc., used on special missions, are not likely to be found on most aircraft in need of a tactical landing system. There would be no justification for extending airborne radar capabilities or adding a new airborne radar to achieve this, since it would be a costly program requiring airborne equipments costing dozens of times what a landing guidance receiver would cost.

The lack of any uniformity in airborne radars used in the Air Force would make any generalized solution impossible.

Different scan patterns (conical, locking, right-left, scan rates, frequencies, beamwidths and display techniques) suggest this would be a generally unproductive area for obtaining landing guidance signals.

Doppler radars, as in the case of inertial and other radars, have drift rates well in excess of the landing tolerances and are likely to lack any uniformity as in the previous case. As in the case of inertial systems, the starting point, and the destination and flight path to the landing area must be established. With typical missions running an hour or so (with the maneuvering that can be expected in tactical environments), the coordinate accuracies needed at the end of the mission for an even localizer approach to, say, a 200-foot ceiling would be doubtful. Of course, no positive reference data for the hazardous vertical glide path is provided by these techniques (airborne radar, doppler, or inertial).

1. ESTABLISHING COORDINATES OF A TACTICAL LANDING STRIP

In addition to these deficiencies of the self-contained systems (when applied to low-visibility landing), the simple problem of establishing the required precise coordinates for tactical landing strips is evident. Often, activities in various parts of the world will take place where maps, surveys, and other pertinent data do not exist. Because of the problems just enumerated, the system cannot be "self-calibrated" to the accuracies required. A small microwave localizer would resolve this problem quite readily since it could cover an area many square miles in dimension. Once the intercept of the localizer coverage area occurs, cockpit instrumentation would display data far more precise, since it would originate at the landing strip and be aligned with it. Heading information for the localizer is needed. Magnetic heading information is adequate in most cases. Other cases can use the localizer beams for crab angle sensing.

This aspect of tactical landing is often overlooked since, in the civil cases, the location of airports is well known, and many coordinate systems (VORTAC) can readily define the location. It is unlikely that this can be assured tactically since about $\frac{1}{4}$ of the earth's surface has few if any such navigational aids.

The logic of the case appears to be that a preliminary flight is necessary anyway to inspect and prepare for use any tactical landing strip. This flight would include the transport of minimal landing guidance equipments (100 pounds or so). The establishment of clearance criteria, runway length, ceilings, etc., is needed before IFR flight and tactical usage of the strip

even in VFR is permitted. The installation in an hour or two of a tactical approach and landing aid would create the necessary set of coordinates for follow-on tactical aircraft. Even in VFR visual sighting of strips, obstacles and glide aiming points are often difficult, so that both VFR and IFR operations would benefit from the radiation of signals establishing the coordinates of the strip.

Although the radar beacons are often used for target location, this is a less demanding job than IFR landing. Furthermore, someone must transport and install the electronic unit to the desired location: be it a beacon or a light weight landing system. The landing guidance would provide course alignment and direction, approach let-down, and clearance over obstacles not practical with a beacon and an airborne radar.

2. TESTING OF TECHNIQUES

Little if any validated flight test data exists for IFR landing guidance of purely self-contained equipments, such as those likely to be found on tactical aircraft. It would seem that some flight-testing should be conducted for those cases where a promising self-contained aid exists. However, for the vast majority of aircraft and missions, a landing guidance receiver would seem a much better solution. Consequently, such testing should have much lower priority than the testing of cooperative light weight beam type landing techniques.

Another problem does exist: that of navigating into and intercepting localizer coverage. These aids may prove very useful in this application rather than landing guidance. Since this requirement is only in the horizontal plane, using barometric or radio height, it can tolerate the errors mentioned previously (a few thousand feet to a mile). Truly self-contained aids, developed solely for IFR landing accuracies are not realizable today or in the foreseeable future because of the large discrepancy between accuracy requirements and performance.

3. POSSIBLE USE OF OTHER AIRBORNE ELECTRONICS

Many tactical aircraft carry TACAN, ILS, and UHF communications equipments. This has led to several proposals and some equipments for modifying these units in some manner for tactical landing guidance. These frequencies are in the 100 to 1,000 Mc region, a most difficult region because of multipath propagation problems. The lack of adequate azimuthal and vertical directivity

(with a small antenna) in this frequency region, makes it quite unsuitable to tactical sites that may well include small areas near trees, irregular terrain, or man-made objects that disturb the propagation path.

Many investigators, having come to this conclusion, are now approaching it somewhat differently with "frequency conversion" techniques. For example, the FAA's program to improve the ILS has resulted in very large (100-foot) structures. These are costly to build and difficult to install. They have requested proposals and will award a program to convert a microwave ground radiated signal, by heterodyning techniques, to the frequency band of the existing airborne ILS equipments. This would require a new family of ground radiators that are smaller, but more readily and economically installed. The (frequency conversion) airborne equipment would include a microwave local oscillator spaced just the right distance in frequency so that the heterodyne signal would appear, for example, in the 330-Mc region of the airborne glide-path receiver.

This approach could be taken with other airborne equipments such as the localizer, IFF, TACAN, etc., whereby a microwave radiation from the ground is heterodyned to the frequencies of the existing equipments by an airborne localizer oscillator. The basic limitation of this approach is that the required airborne and ground units are expensive without achieving the major benefits that could accrue from adoption of a microwave landing system. The constraints of the modulation characteristics of these other systems, and the need to make the microwave beams emulate the VHF beams or signals are much too inhibiting to good system engineering.

The airborne antenna installation, local oscillator, and its channelization equipment make up the majority of the elements of any microwave landing equipment. The savings come only in the channelization and demodulation sections, since the same cockpit instruments and flight directors are likely to be employed in either case.

Because of these factors, ILS-microwave frequency conversion schemes will not work out too well in the long run. Their application to tactical landing problems will probably be stressed by the FAA or others. As noted in the sections on landing measurements and system design, the characteristics of the beam patterns, modulation, etc., are inadequate since they are all fixed by the ICAO-ILS or similar (tactically unsuitable) standards. The phasing out of these equipments in future years is also probable, so that dependence on them should be avoided. A fresh approach to tactical landing systems with flexibility of paths, and functions is needed.

4. AREA COVERAGE SYSTEMS

The low frequency (LF) systems of Decca, Loran C/D, and Omega, are often used for military applications. Decca normally uses a short baseline of 100 miles or less, and Loran C/D uses a baseline of around 1000 to 1500 miles. The Omega system uses a baseline of about 4000 to 5000 miles and will cover the earth's surface with several lines of position (LOP)--about 5--with only eight transmitting stations. For the same coverage, Decca would require thousands and Loran C/D hundreds of stations. In cases where such aids operate they can be used for locating and intercepting the coverage of the localizer of the landing system.

The problem that presents itself, however, is that, though quite useful, such low frequency signals may not be available. Only Omega is global in nature. The other two low frequency systems will cover only a small portion of the earth's surface. Large water areas are covered only by Omega, since siting is impossible for the other systems, particularly Decca. Omega is now operating with four of the stations and sufficient data is being gathered (past 10 years) concerning its performance that it now holds the greatest promise for a global area system. Although Loran C/D is probably the best instrumented U.S. system today, the large number of stations and the requirements for locating them on foreign soil or water sites creates nearly unsolvable technical and political problems.

Although it is currently primarily of concern to the Navy (submarines and ships), the enormous baselines of Omega, and the flexibility of station location because of this feature would make it of considerable interest to the Air Force. Current FAA and Navy flight testing into South America, Alaska, and elsewhere, has been encouraging according to reports.

Because VHF and UHF (or above) are limited to line-of-sight transmissions, hundreds of ground facilities would be needed to give area coverage in most theaters of operation. Often the terrain or desire to fly low "nap of the earth" profiles further reduces the operational coverage of area navigation in this part of the spectrum.

It is, therefore, probable that during the forthcoming years more of the services will use navigational methods suited to large areas with few or no new ground facilities. The basic mission of MAC assumes a global airlift capability that is dependent on global navigation and IFR landing in remote parts

of the world. The satellite navigational systems have limitations, since the navigation signals appear infrequently, whereas often continuous track information is needed. Satellites also tend to have very low powered signals, multi-path signals (to earth-to aircraft), which can often garble intelligence.

5. DIFFERENTIAL OMEGA

As noted, Omega is the only system that is capable of true, economical global coverage. No new installations will be needed for any specific tactical purposes, no matter what remote part of the world is involved. Since it operates on low frequencies (around 10 to 12 Kc), it covers down to the surface of the earth, and good reception is even practical below the surface of bodies of water. In the past, Omega has not been commonly considered for accuracy because of its diurnal (day-night) error effects. These are caused by changes in propagation that occur during the day when the reflective layers change somewhat in height. The uncorrected error is often a mile to several miles. Interestingly though, this error is readily computed and correction tables are now available for determining the exact amount of the error at different locations. The Omega tables permit local corrections to fall well within a mile or less.

A far superior technique just reported by the Naval Research Laboratory "Differential Omega" (references 42 and 43) uses a monitor receiver. The receiver determines the extent of the diurnal change, and this information is sent to the users of the Omega signal in the vicinity. Initial tests show errors as low as $\frac{1}{4}$ mile (1500 feet). Continuing tests indicate that errors of $\frac{1}{4}$ to $\frac{1}{2}$ mile in an area about 100 miles around the monitoring receiver will be realized. Since the Omega receiver can be a small battery-powered solid-state unit weighing a few pounds, it could readily be used at the landing strip region for correction of the local grid lines. If located with the localizer, the errors become less as the aircraft nears the landing area. Rendezvous accuracies of 600 feet have been measured.

Since the Omega stations are so far apart, the lattice lines are parallel to each other over distances of 50 to 100 miles, so that complex hyperbolic computation is avoided.

Thus, it would be possible to include with the landing equipment a small battery powered unit for Differential Omega with the correction transmitted over the communications link, required anyway for ATC or aircraft intending to land. Since there are five LOP's at key locations, the fixing of position

is somewhat overly compensated for, and the loss of a station is not significant. With stations thousands of miles from the actual area of utility, enemy action is not likely to result in their loss as is possible with short-based systems that must be located in hostile areas.

The simplicity of both the air and ground systems makes Differential Omega attractive. Simple receivers operating in the 10 to 13 Kc region (upper audio) that would supply linear non-ambiguous data for about 50 some miles around a differential station might serve in the many parts of the world where Loran C/D or Decca is not available (over $\frac{1}{2}$ of the earth's surface would have only Omega). The concept of a terminal area system available everywhere on the surface or at any altitude is most appealing when considering a means for the terminal area feed to the tactical landing system. Furthermore, the same airborne equipment would be useful for global navigation and terminal area guidance.

6. SUMMARY OF FEASIBILITY OF USING OTHER RELATED GUIDANCE TECHNIQUES

To attempt to use area systems or purely self-contained systems for the extreme (relative) accuracies of the landing operation does not appear feasible. To use low-frequency area systems, however, to complement the tactical landing system by providing guidance into the coverage of the localizer can be a valued contribution. It removes the burden of adopting the typical, terminal navigation facility such as VORTAC (TACAN and/or VOR) that is hard to install. It further permits a reduction in the requirements for the azimuthal coverage of the localizer. Experience has been that the more restrictive coverage of the localizer usually results in simpler siting and much better performance (it minimizes reradiation that can degrade the course quality). If the localizer had a coverage of around 90 degrees and a range of 10 to 20 miles, the total area covered could be many times larger than the accuracy of a low-frequency system, so that the low-frequency system could readily be used for locating the localizer. Flights from a distance of even thousands or hundreds of miles could terminate well within the localizer coverage with Differential Omega. Costly inertial units would not be required for this function. This plan would permit low-altitude as well as high altitude operations, since low-frequency regions are not limited as is VHF-UHF or above by the radio horizon. Thus, missions could be planned that are not restricted by propagation coverage, and only arrival to within the microwave signals would then assure that sufficient height is maintained to clear obstacles in the approach zone of the localizer and somewhat beyond.

Even in cases of short final approaches of 5 miles or less (perhaps 2 miles with helicopters), it is likely that the same interface between the low-frequency navigation system and the microwave landing system will work satisfactorily. Since the microwave system is highly portable and the low-frequency system is as permanent as the earth's magnetic field and as readily available, the lead time for preparing for a mission (say a global airlift to remote parts of the world) can be greatly reduced--to hours, not weeks or months--and the cost minimized. Since the large Omega transmitters would already be in operation and far removed from hostile areas, the five lines of position would exist everywhere, and the enemy's ability to deny the service would be remote. Similarly, the microwave system's vulnerability is low because of its limited coverage and rapid deployment.

SECTION V

PREVIOUS GOVERNMENTAL ACTION IN ESTABLISHING TRANSMISSION SIGNAL STANDARDS

As noted in Section IV, several electronic techniques for tactical landing are under consideration that are incompatible and exclusive of one another. This is not new in the history of electronics. Controversies over electronic systems, such as the Decca-VOR, Tacan-DME, and TDL-FDL (data links) have occurred in the past, and have been resolved by one means or another. However, an example with many more similarities to the tactical landing case is that of color and monochrome television. Only one set of standards, for both monochrome and color evolved. Here three incompatible electronic techniques for color came into conflict and a single standard finally evolved after several years.

Several of the examples of the past did not involve the electronic compatibility and mutually acceptable requirements of the two conflicting services. In fact, the resolution of these previous conflicts has often been a costly side-by-side operation of both systems. The finesse of obtaining two services from the same set of standards typifies what is needed in the case of tactical landing signal standards.

Since the ICAO-ILS will be assured and utilized by some segments of the Air Force for many years, several efforts have been made to utilize it for tactical purposes. If the Tactical Landing System could use the same airborne equipments, much could be saved and rapid progress made. However, since the ICAO/ILS frequencies and beam modulation techniques were standardized some twenty to twenty-five years ago, the growth potential simply has not evolved and probably does not exist. As noted elsewhere, the ICAO-ILS developments have been away from, rather than toward techniques suitable for tactical landing.

There is danger that several different and incompatible tactical landing systems will evolve in the next few years. The recognition of the shortcomings of ILS and GCA has encouraged a rash of new uncoordinated developments.

Thus, the challenge at the moment, prior to commitment to any of these candidates, is to establish a single standard that will meet all of or the greatest number of tactical landing needs. Such a standard will obviously be biased by the requirements, state of the art, test results, and analysis. However,

to act without establishing a single standard will create conflicts equaling or exceeding those of the past. A study of a case history (such as monochrome TV standards) removed from the military electronics area, but very similar to the philosophical requirements of a common Tactical Landing System is instructive. It permits an appraisal of the reasons for such conflicts due to sophisticated electronic incompatibilities, the costs involved, and the complexities of the forced industry-government resolution of such a conflict once it is permitted to develop.

From this experience, it is apparent that such conflicts can and must be avoided at early stages by prompt and decisive action. Without such action, the costly, wasteful delays involved in the proliferation of several tactical landing systems will continue.

The standards for monochrome television transmission and reception were well-established prior to the proposals of three incompatible color transmission schemes. The large investment in monochrome transmitting and receiving equipment on a national basis eliminated the possibility of a complete revision of standards. One initial thought was that a new set of frequencies could be made available for color, since it was believed that more bandwidth (than a monochrome channel provided) would be needed. Competitive techniques of "Dot," "Line" and "Field Sequential" were adequately developed to the stage where the industry and government wanted to proceed with public service. However, it became evident that the signals of the three systems were "mutually exclusive" and that no means could be found to permit the introduction of all or even two of them. Channel limitations forced the consideration of color techniques requiring minimum bandwidth.

After extensive hearings, and several years of demonstration, the Field Sequential System of CBS was officially adopted by the FCC. Manufacturing was started and dozens of station permits issued for the transmission of this standard. However, certain limitations of the system became evident, and it was decided after a period of time (about two to three years) to reconsider the whole matter.

The initial color television issue of the Institute of Radio Engineers (I.R.E.) in 1951, indicated that all was not well, and intensive research testing and highly competitive industry activity was begun. By this time, a quasi-official committee of engineers and scientists known as the NTSC (National Television System Committee) produced what are now the signal standards for compatible color and monochrome transmission. In the process, the FCC withdrew its prior approval, the United

States Senate was deeply involved, and a battle royal among the giants of the electronics industry took place.

In retrospect, the earlier FCC approval was evidently not acceptable, operationally, technically, or otherwise, and the subsequent extensive testing, and industry research and development showed the way to a competitive system standard that was superior. In short, the necessary technical developments and testing were finally concluded, and an administrative decision had to be withdrawn at the highest levels of government. The part of the television report pertinent in certain respects to the resolution of the Tactical Landing System Standards is briefly reproduced below:

"The three systems are mutually exclusive. One and only one, of these systems must be chosen in advance of the inauguration of a public color transmission service."

(September 1950 Proceedings of the IRE: report of the Senate Advisory Committee on Color Television.) This report was the result of Senator E. C. Johnson's request for a technical investigation. He stated:

"(Color TV) has been a matter of raging controversy within the radio world for many months. Hundreds of applications for television stations are affected. There is a woeful lack of authentic and dependable information on this subject."

The major technical considerations needed to resolve the conflict according to the report to the U. S. Senate were:

- a. Television scanning: "reading" the content of the scene.
- b. Pictorial detail: how many dots in the picture?
- c. Image continuity: how many pictures must be transmitted per second?
- d. Natural vision versus television (human factors studies were important).
- e. Channel width: how many megacycles for a television station?
- f. Color fidelity: how true is the color reproduction?
- g. Relation of color service to existing black and white service.
- h. System characteristics (resolution, flicker, continuity of motion, effectiveness of channel utilization, costs, etc.)

Various systems were rated by this select committee based on these characteristics to establish some guide lines for the resolution of the impasse.

One can readily replace phrases of this report with those relating to a tactical, multifunctional landing system. Pictorial detail is similar to course quality, lack of bends, non-linearity, etc. Image continuity is equivalent to the adequate updating of the guidance signals, smoothing of the guidance data, or the number of fresh samples per second from the guidance beams. Channelization, number of channels, efficient use of channel widths, etc., are directly related. The technical detailing of the system characteristics--lines (beamwidths), elements (DME-accuracy), modulation signals, signal strength for good reception--are further examples of this analogy.

Thus, it would seem appropriate to examine this and similar examples in detail. Perhaps, the "model" of its methodology could be used to establish the committee organization, the means of writing standards, the inter-agency procedures, etc. The organized method of dealing with a controversial subject such as the Tactical Landing System should be established before getting involved in costly commitments that probably cannot be fully justified in later years. The success of the color monochrome TV standards came about primarily because a set of multifunctional standards was developed. These standards permitted the continuation and expansion of monochrome while the details of the more complex color system were being worked out. It has taken nearly a decade before these standards have reached an advanced stage of utilization.

The similarity with tactical landing systems (1) that can adhere to a common standard, (2) that have growth potential for more sophisticated uses, and (3) that do not deny the more basic and simple early applications is evident. Another encouraging note is that, until this standard was accepted, there was no major investment by industry for production facilities toward capturing some of the market. The industry participation in a tactical landing system development is, of course, essential.

However, until standards are agreed upon, the industry will either shun the field because of its uncertain nature, or powerful adversaries with competing techniques will develop. Furthermore, without such standards there is no assurance that any tactical landing system will meet operational needs. With at least three current incompatible techniques, and no standards for tactical landing, results are certain to be divided government agencies and wasteful expenditures, since none of the systems are likely to survive (as did ICAO-ILS). Such was the case of TACAN-DME wherein the same channels were in contest involving widely different channelization schemes (clear channel vs pulse multiplexing channelization). The VOR and Decca, being on widely

different frequencies and generally in different parts of the world, have continued in use.

Another significant result was that once a quasi-industry governmental position was taken which had sound technical backing and proof of performance, all parties soon dropped their differences. CBS found it had as much to gain eventually as RCA by the exploitation of the agreed-upon standards. A large investment for manufacturing, testing, and transmitting these signals was then made, and a useful system resulted. A protracted impasse was a real threat had the entrenched positions solidified to such an extent that there may never have been a resolution. The current European color standards are indicative of how serious it could have been. Negotiations between the U.K., France, and Germany to find a reasonable standard for even monochrome continues, and the differences of line structure, bandwidth, and other details may delay this matter many years, since each country is firmly entrenched and little overall discipline can be exercised.

Another example is given in the discussion in the October 1966 IEEE Spectrum about the compatibility between fundamental communication techniques, telephone dialing, cables, and satellites, now all being integrated into global communications networks. What appear to be simple technical considerations, create global incompatibilities. Comsat and the United States Military each presented views in this Engineering Journal, as did several scientists. The physical dials used and the number of digits for a global dialing system must be resolved and dozens of regional, state, and international meetings are under way with the objective of reaching some common standard on this simple matter.

A new dial system (No. 6) has been under study for many years and, if adopted, will stand as a prime example of international cooperation. The International Telecommunications Union (ITU) continues to have standing committees, many working for years on these and similar standardization problems. Many are now taking a different meaning with satellite and other global systems that are not tied to the limited standards of the past. Other technical standards relating to sub-carriers, channel spacing of carriers, coaxial line systems, digital signals, transmission units, data transmission, and radio telephony, differ from country to country or from one region of the world to another.

In this field of global communications, many years of independent development to meet individual needs were partly to blame for such incompatibilities and the fact that several decades have solidified these separate standards. Standards must

be developed before large investments are made in individually, narrowly conceived systems that are incompatible in what will inevitably be a common environment. The large number of individual communications equipments create vast additional costs for signal translating equipments, interfacing (changing from 525 to 625 lines per television frame), etc.

Technology today should permit a matter such as the resolution of the many tactical landing system candidates to be much simpler than in the past. We have the experience of the past as outlined here, and we have more powerful electronic "tools," more versatile radio frequencies, and the real need (and what seems to be an intent) to succeed in this case.

However, many individuals new to the technical aspects of IFR landing, particularly from the aeronautics field, do not know this history and do not realize the additional complexity of designing a cooperative electronic system as compared to an aircraft design. Usually, one mission determines a single airframe-engine combination. The tactical landing standards must ultimately involve most Air Force aircraft, diverse types of aircraft and missions, and even other agencies. This is not at first apparent to many familiar with other types of decisions, and impatience calls for action that can be catastrophic to a subsequent second or third decision that must inevitably be made. It is essential at this time to envision the tactical missions in their varied environments and the aircraft types needed to conduct them, so that a flexible multi-functional landing system can evolve.

As in monochrome TV, it may first result in a limited system, but it should have growth potential to the more sophisticated applications that can be envisioned. A tentative step is taken in this report in Section VII on the "synthesis" of such a system. The methodology for making the basic technical decisions for standards of a multi-function tactical landing system is outlined there.

SECTION VI

AIRLIFT CONCEPTS AND ALL-WEATHER LANDING

Although many of the other missions of the Air Force are equally significant, the airlift mission is discussed in this section to portray the interrelationships of such missions to the tactical all-weather landing needs. The airlift concepts are both strategic and tactical in nature. A large expansion of airlift capacity is now under way. However, the tendency is to design aircraft that will have both capabilities. Consequently, tactical landing solutions are of direct concern to the future success of expanded airlift capabilities. A good way to emphasize this is to review a report on current Air Force planning in this area.

The recent (1966) House of Representatives report "Military Airlift," based on hearings of the special subcommittee on airlift, provides insight into the nature of the Air Force and DOD programs in this tactically significant area. For example:

"The basic and primary mission of the C-5 will be the rapid deployment of balanced combat forces and firepower along with supporting elements to any specific area of the world. The high flotation landing gear and relatively short takeoff and landing performance will provide the capability to deploy forces into support airfields with relatively short runways, and unimproved airfields."

This is a partial quote of the statement of Major General R. J. Clizbe, USAF, before the special subcommittee on Military Airlift, of the Committee on Armed Services, October 1965 (page 6637 of the Hearings).

From the same report, Secretary of the Air Force H. Brown stated:

In many instances, aircraft such as the C-5 and the C-141 will deliver directly to the forward, logistic bases, rather than main logistic bases at the rear, depending, of course, on the suitability of landing zones."

"More than 15,000 troops and 440 tons of equipment were airlifted to Germany in 63 hours, this was back in 1963, to marry up with prepositioned equipment."

"Wartime or emergency capability will actually more than double between now and the time in which the C-5A is introduced, late 1969, and again by 1972, that is double again after that, when the first three squadrons of C-5A's will come in. So actually, there will be an increase by a factor of 10 between 1961 and 1971 or 1972."

"This dramatic increase in our capability to project our power rapidly in order to meet contingencies anywhere in the world will have far-reaching effects, both military and political. It will be a major deterrent to non-nuclear aggression, just as our Strategic Air Command is the major deterrent to nuclear attack."

"The ultimate objective is to achieve a one-step delivery from the main logistic base to the consumer."

Now the capability to deploy quickly rather large and balanced military forces, to any spot on the globe, reduces the probability that major military contingency actions will be forced upon us. However, should they occur, their cost is reduced substantially in terms of total military forces required, duration of conflict, casualties suffered, and dollars expended. Airlift is becoming an increasingly productive partner on the global military team.

1. AIRLIFT CONCEPTS AND ALL-WEATHER LANDING

With the development of such aircraft as the C-130, C-141, and now the C-5A, the pattern of a realistic global airlift capability takes form. Such aircraft will be able to airlift equipment and troops rapidly, into a critical part of the world before serious difficulties can develop. If weeks of preparation of strips to make them useful in all weather and at nighttime are required, these objectives will be denied. Nor can the need be satisfied by limiting the operation to only those large airports where full visual and electronic aids exist for final approach and terminal control. Since airlift performance is measured in hours, including hours of darkness or IFR weather, the ability to land at night or in IFR with minimum or no approach lights is important. This places a requirement on the tactical landing system to replace the dependence on lights with dependence on good radio guidance. The forward strips or the thousands of small landing fields in remote parts of the world (that are already built) will not have these aids. A rapidly installed, but fully flight-validated electronic centerline guidance signal and glide slope can do much to minimize the need for the time-consuming and bulky lighting systems now used. Furthermore, for CAT II and similar low-visibility landings, very little of the lights can be seen anyway. The cost, power consumption, and bulk of these lights are beyond the tactical, quick set-up concepts of tactical development. This will place additional requirements on the low-visibility landing system. The localizer, in particular, will be used more extensively, and additional signals are perhaps needed, such as threshold location.

Little research has been conducted on this problem, since the entire history of instrument flight to date has assumed a 3000-foot long string of high-intensity (or similar) approach lights. Threshold, perimeter, and centerline lights are often added. These are far too heavy and complicated to be considered for a forward base. A simple one-unit lighting aid such as the Navy "meat ball" might be given some consideration, since it is portable and the "mirror" version is trailer-mounted. It now works well enough to provide a vertical, straight-line glide slope from a distance of 1.5 miles. Its main virtue in this modified application would be the provision of at least one light source that the pilot can acquire and use for establishing visual contact. It would be a "heads-up" signal in the sense that it could be modified to be useful for the last fraction of a mile for correction of displacement and rate to the desired touchdown point.

Night flight research, using the portable straight-line electronic glide slope with the meat ball could establish the feasibility of this minimum approach. Modifications will suggest themselves as a result of these tests.

The main point to be made is that the current instrument-rated AF pilot expects lights and is dependent on them today even at rather high ceilings. Some of the lower ceilings and visibilities hopefully to be achieved with the tactical landing program must consider this.

The desire of any pilot flying under low visibility conditions to see ground references with his eye is overwhelming. Without lights (approach and standardized units), at a strange strip perhaps for only the first or second time, at night or in foul weather, establishing a high confidence level will be difficult but is essential to transport airlift aircraft in the tactical environment.

The Air Force mission in airlift includes "air transportation for personnel and cargo for all the military services on a world-wide basis." (U. S. Government Organization Manual). The recent years have seen large production of the C-130 series of aircraft, the C-141, and now the enormous C-5A. Many other transport type aircraft still are operated but around 1971, a full jet-powered fleet of 4000 to 5000 aircraft will exist. This program, which will cost several billion when fully implemented, will give an airlift capability to any point in the world in a very short time. The large savings gained by reducing standing forces from many locations over the world will make this more than attractive for future years when small brush-type

warfare can occur almost anywhere. The requirement for immediate action measured in hours demands full consideration of IFR and night landings in minimum landing fields before such a tactical concept can succeed.

The normal shipping of troops, supplies, etc., often takes so long that much valuable time is lost before a force in strength exists. Timing of action can be the difference between the large military battle versus a small one or none at all. The exercise of this type of support in about 1963 saw the effect of weather. The thousands of troops sent to Germany on maneuvers, in hundreds of aircraft (of older vintage) nearly did not succeed, since the Frankfurt (Germany) weather went below minimums for several hours and flights were diverted to England. Fortunately, however, the weather improved just in time to resume the exercise so that on a longer-term basis, around 50 to 60 hours, it was quite successful and indicative of the future.

It should be clearly noted, however, that this was an exercise going into major civil or military fields with long runways, ATC, lights of every type, GCA, ILS, TACAN, etc. Although there are many major bases around the world, the basic ILS (ICAO system) itself is probably too marginal for large aircraft of the C-141 and C-5A type. Furthermore, it is installed at only about 10 percent of the world's air carrier airports (service reported in Airline Guide). Many problems of CAT II ICAO standards are becoming evident and no hard, successful, operational experience exists (reference 21).

There is serious doubt that a 100% capability can be achieved in these foreign locations with ICAO-ILS. A less costly solution, that is safer, consistent, and requires uniform training should be substituted.

Even early microwave landing systems (Sperry 2600 Mc) have been deployed in a matter of two hours, establishing a fully satisfactory landing service that would take weeks to establish with ICAO-ILS. If each potential ICAO-ILS in various parts of the world is to be updated to CAT II standards for the execution of global airlift policies, this will cost many times the development and production costs of portable, superior, microwave landing systems.

A rapid military build-up, where thousands of troops (thousands of cargo tons) requiring hundreds of aircraft to operate on a shuttle basis 24 hours per day, requires some forethought and pre-flight planning. One of the first steps would be to fly the microwave landing system to the various bases

(civil or otherwise). A C-130 or C-141 can readily do this. If dispatched early, this mission could be delayed itself by weather a day or so and still arrive and have a landing system in place prior to arrival of the main airlift. The aircraft upon landing is used to place in position on the runway edge the vertical landing guidance units and is then similarly used at the roll-out end for placing the horizontal guidance units. The guidance unit could be either of modular design with a large antenna, capable of approach and flare guidance or a smaller, single path (no flare) unit (see section VII).

After being placed in position, and sited by a responsible individual who has accompanied the equipment, the same aircraft is used for the flight inspection. The flight inspection will be standardized and the support aircraft will have the trained personnel and recording equipments to achieve this objective. It is estimated that within 2 to 3 hours after landing, a fully flight-inspected landing system could be operational. Depending on modular designs, it could include full flare and roll-out guidance and GCA. After preparing this function, the single C-130 would depart for a second similar mission to another strip in the area. Thus, the Air Force could pre-position, in strategic locations around the world, portable microwave landing systems so that a number of units could be within 1000 to 1500 miles of the tactical strips to be employed for the airlift. Periodic exercises would minimize the initial installation and commissioning time.

The crews would be specially trained during peacetime, and the C-130 aircraft would fly to many strips in various parts of the world and install, flight test, and remove the landing system. In this manner, the training, siting, etc., would have been logistically assessed before the notice (with short lead time) for an installation and commissioning of a tactical landing system is received. A cost-benefits study should be conducted on this or a similar concept. The input parameters would include the cost to attain CAT I, CAT II, or CAT IIIA (ICAO-ILS) at a sufficient number of remote bases to assure a realistic landing capacity for the global airlift concepts. Similarly, a study should be conducted assuming a transportable microwave ILS. The flight inspection costs should be less for microwave ILS since it is less susceptible to reflections, course bends, etc., and should be qualified for a given operation more quickly. Microwave glide-path settings can be quickly established, and an electronic obstacle clearance line can be radiated by the same equipment at a low angle to clearly warn the pilot of any restrictions. Probably, the benefits provided by not leaving the system after installation, and removal with minimum effort would be the greatest attribute of the microwave system. Usually, ICAO-ILS

(330 and 110 Mc equipments) are permanently installed because of their great bulk and installation problems. When CAT II is considered at poorly prepared sites, only the most modern 100-foot waveguides or directive antenna systems are suitable in the ICAO-ILS field.

Ultimately, the large airlift capacity should be able to operate under night and IFR conditions at literally thousands of air strips around the world. To be justified economically, it will be possible to equip only those sites that are essential to a specific operation. Consequently, techniques suitable for rapid installation must take priority over the currently employed ICAO-ILS.

2. THE C-5 AND ALL-WEATHER LANDING

As far as can be determined, no plans for night and IFR landing guidance along the lines previously discussed are currently being implemented. It would seem that the loss of a single C-5 aircraft with 800 troops could be a national tragedy. The airlines are considering the ultimate loss of a 747 being an insurance risk of over 100 million dollars. The self-contained means of accomplishing the C-5 mission are very unreliable when considered on a global basis. It would seem that this project alone would justify a high-priority examination to determine how these aircraft can be realistically deployed into the forward strips for which they are designed. They have a tactical landing need that may not be immediately apparent but that is as great or greater than any other type of Air Force mission.

The value of these large aircraft is to move cargo and troops on a sustained flow basis to any remote part of the globe. Comments on global systems such as Omega (Section IV) are pertinent to the 5500 mile range capability of this aircraft. Inertial navigation units need updating from sources that do not have similar errors and drift rates. Thus, Omega and inertial navigation would marry for the guidance to a small area anywhere in the world wherein the need to land becomes of paramount importance. Since about ¾ of the earth's surface has little or no navigation aids, only global systems would seem worthy of consideration.

Thus, the ability to get within the vicinity of the desired landing strip can be fulfilled. However, the inability to predict the time of the mission, the terminal weather, and the likelihood of darkness will prevail for half the time; this infers that a much higher guarantee of instrument landing must be provided. The enormous potential loss of a single landing accident, when added to this argument, suggests that much more

consideration be given this problem than is the case at present. Portable microwave systems installed at strips in the area would be channelized for identification of the particular strip and would have sufficient horizontal coverage to overlap several times the probable error of the Omega-Inertial type of enroute guidance. Differential Omega would offer a terminal guidance aid utilizing the same equipments employed en-route for intercepting (at the correct distance and angle) the microwave localizer coverage.

Remembering that the pilot may not have flown in the particular part of the world involved, and certainly not landed at the particular site, the standards of en-route, terminal, and landing guidance must be the same everywhere. Consistency of guidance permits continuous training that typifies actual missions. Landing guidance accuracy requirements far exceed those available from inertial, Omega, Loran C/D or any similar systems (including those using satellites). Thus, the overall mission concepts of the C-5 must allow for accuracies that improve to the point that near touchdown they are measured in feet, not in hundreds or thousands of feet; typical of en-route systems. Portable, microwave landing techniques seem best suited for this requirement with today's technology.

SECTION VII
SYNTHESIS OF A MULTIFUNCTION
TACTICAL LANDING SYSTEM

1. METHODOLOGY

A step-by-step procedure (Figure 36) for determining the technical nature of a tactical landing system will be outlined in this section. The previous sections have discussed various aspects of the Air Force tactical landing problem. This section attempts to describe a logical means of applying knowledge of operational needs, landing profiles, and similar inputs to the choice of a radio frequency for the system. Section III detailed some of the fundamentals of landing guidance by cooperative methods. These fundamentals, and the range of flight paths expected for the different types of aircraft provide guidance in selecting the radio frequency.

Modulation techniques are then discussed since the angular paths either vertical or horizontal must be identified by some means of ground modulation of the radio signal that varies with aircraft position. The question of how best to achieve a tactical DME is noted at this stage.

Once these matters are understood, it is possible to establish a "Signals-in-Space" standard. This standard allows for minimum equipments for some aircraft and missions and more complex equipments for more demanding aircraft and missions. Hopefully, there is sufficient insight to also provide growth in future years.

Next, in step 6, modular designs are suggested that can serve as building blocks for different operational system configurations, some of which are described in step 7. Steps 8 and 9 relate to the eventual procurement and interfaces with other services and civil operations. The global nature of Air Force operations must recognize, even for tactical problems, the existence of an International Civil System. Their relationship is of significance.

2. STEP I--OPERATIONAL NEEDS

There is a wide variation in the types of aircraft and missions flown by the Air Force. They include nearly every basic type of aircraft, every type of military mission, and are

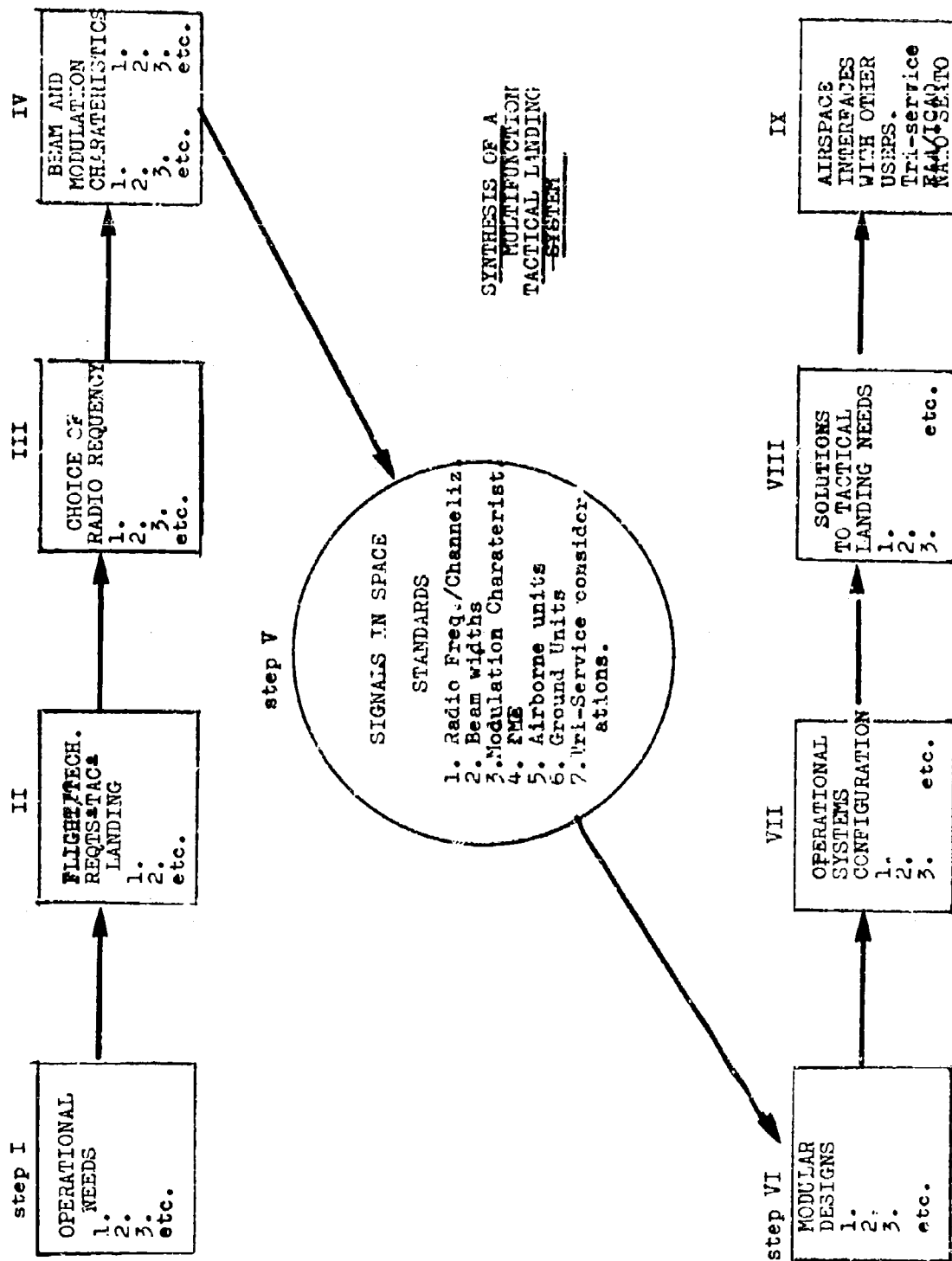


FIGURE 36. SYNTHESIS OF A MULTIFUNCTION TACTICAL LANDING SYSTEM

global in nature. This contrasts with some of the other Services that concentrate essentially on one type of aircraft. The impressive airlift to Germany (Big Lift, Texas to Germany) in 1963 moved 15,500 troops and 425 tons of cargo with 204 aircraft, flying 234 missions in 63 hours. 42 C-5A aircraft could accomplish this operation in only 13 hours or 128 C-141's in about 40 hours.

The smaller but versatile C-130 is able to interface with the larger aircraft (such as the C-5A or 747) and continue the airlift to the minimum of landing sites. The airlift fleet totals over 4000 aircraft.

The jet fighter is used extensively for Air Defense, and in fighter/bomber missions from the tactical landing fields. The ability to utilize fighters without regard to weather or blackout is important. However, most current fighters have serious "GPIP"* limitations (references 34, 93, and 94). The V/STOL aircraft are about to be introduced for many missions. The helicopter is also used in Air Force missions, and is the basic aircraft for most Army missions that interface with the Air Force missions.

When one examines the missions of even a single type aircraft, one finds they can involve many types of landing sites. It is, therefore, difficult to define a simple mission profile and landing requirement. The helicopter has many varied missions with steep approach angles terminating in very short landing distances (50 to 100 feet), whereas the Air Force jet fighter normally takes about 4000 feet to flare and touch down from a 100-foot height. A large volume could be written on this subject. However, suffice it to say that a more detailed study and measurements will be needed to make sure that all reasonable flight paths and accuracies can be met with the modular, multi-function, Tactical Landing System. In this way the mission planners themselves become aware of the value and enhanced utility of their aircraft utilizing such equipment. Figure 37 gives three examples of the matrix (reference 27) that can be developed for different missions for a single type aircraft. The common airborne equipment employed in the operation might cooperatively utilize one type of ground equipment for air drop, another for a steep approach, and a combination for a very low visibility landing at a rear base where good clearance exists.

The Air Force support of the Army is extensive in many ways such as major airlift, forward air control, tactical airlift, etc. However, the Army itself will have thousands of helicopters in operation shortly, and an important operational

* Glide path intercept point

Aircraft Types

A/Liason
 B/Helicopter
 C/Utility
 D/Jet Fighter
 E/V-STOL
 F/Bomber(tactical)
 G/Cargo
 H/COIN

Landing Sites

A/Assault Zones
 B/Rapid Sites
 C/SATS
 D/Bare Bases
 E/Carriers
 F/Forward Bases
 G/Main Bases

Missions

A/Landing
 B/Resupply
 C/Evacuation
 D/Paradrop
 E/Close Air Support
 F/Assault Forces
 G/Tactical Airlift
 H/Strategic Airlift

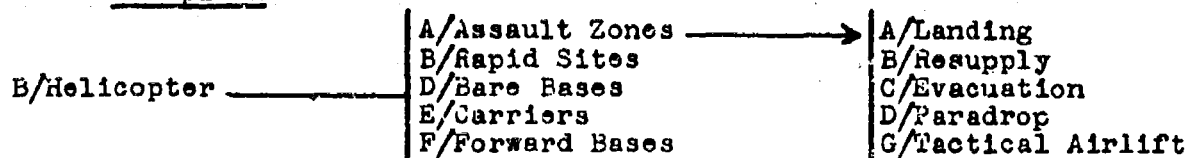
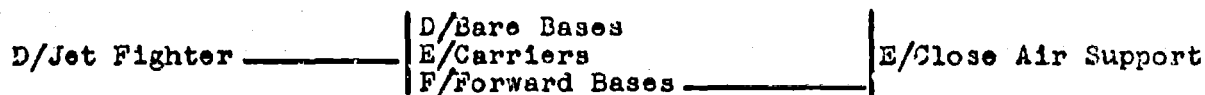
Example 1Example 2Example 3

FIGURE 37. SYNTHESIS OF A MULTIFUNCTION TACTICAL LANDING SYSTEM
 (Step 1)

interface exists between the two Services. Certain areas will involve common landing strips and a technical compatibility of "Signals-in-Space" (reference 61) is essential not only with the Army but with other services for similar reasons.

This step in the "Synthesis" of a Tactical Landing System must assume that various aircraft missions and landing sites are considered. This may be an internal staff study or an external one, but mission profiles for the terminal areas, say 30 miles, 10 miles and then the details of each of the landing profiles should be developed. Obstacle clearance lines should be established for a variation of Tactical Landing Sites. A section on available measurements of a variety of aircraft follows to illustrate this matter.

a. Aircraft Statistics and Relationship to Tactical Landing

The total aircraft inventory of the Air Force, and related Services that will be affected by a Tactical Landing System capability is very large. By about 1970 the airlift aircraft will total about 5000 in number with the payload increasing rapidly so that the total capacity will gain about ten times over the early 1960's capacity. By then airlift aircraft will be mostly jet-powered. The need for many tactical (short field) aircraft such as the C-130 (about a thousand) to support a field battle area of Army or Air Force personnel requires the ability to fly at almost any time to any reasonable landing clearing. On the other end, the enormous C-5A will be able to carry vast supplies to great distances (50 tons to 5500 miles) at jet speeds.

Both are the typical life line of the new military strategy and make the need for a guaranteed landing at the overseas desired location much higher than in the past. Since global activities are the justification of this multibillion dollar fleet and support staff (100,000) people in MATS: mobile, air transportable, flexible and highly reliable landing systems are essential. Installation and commissioning in hours is essential, not days, weeks or months as it is today with ICAO-ILS.

The Air Defense and Tactical Air Commands continue to be charged with important missions. These or similar missions will probably be essential for many years. A fleet of about 3000 "Century Series" aircraft (F-100 to F-111) is now operational in TAC and ADC. Typical of this family of aircraft is the F-101, which is currently restricted to 300-foot ceilings

and excessive horizontal visibility criteria because of the improved siting of the GPIF, of the GCA, ILS, and VASI approach aids (references 34, 35, 36, 64, 82, and 93). By relocating the GPIF, which is the approach aiming point (see the discussion on landing parameters), the ceilings and visibilities could probably be safely reduced to 100 feet and $\frac{1}{4}$ mile with attendant improvements in safety. The operational path actually flown is often 75 to 100 feet below (reference 82) the intended glide path (MRN-7/MRN-8, GCA VASI). Consequently, the Air Force fighter pilot is not provided quantitative guidance when he needs it the most. He abandons the guidance at about 300 feet and "ducks under" with increased vertical velocity and crosses threshold at about 8 feet rather than the 40 to 50 feet of the ILS standards.

Basically, new criteria must be quickly developed for the jet fighter and new guidance concepts applied. Approach aiming points about 2000 feet forward of the present ones, a positive means of checking altitude (independent of approach terrain), and a "positive," safe path indication for flare (to avoid striking short) will result in a touchdown at about 1200 feet in from threshold (see data in measurements section). Currently, if the aircraft is restrained on the glide path to a 100-foot height and is not permitted to increase sink rate (but must obviously reduce it at this point), the touchdown is often 2100 to 2400 feet beyond the intended GPIF (references 36 and 94). Since the GPIF is usually about 1000 to 1200 feet inside the threshold, this places the main gear touchdown up to 3500 feet from threshold.

To avoid such overflying of essential runway, the pilot is left, at present, in a serious dilemma. He cannot "duck-under" when the approach speeds are upward of 160 to 195 knots under IFR conditions, and if he holds the path he touches down much too far along the runway and may go off the end or into the barrier--denying the runway to the subsequent aircraft for a significant time.

The SAC problem, though not so much involved in the decisions of a tactical landing system must be given some consideration so that some Air Force commonality exists. The current ICAO-ILS is used by SAC with GCA (references 22 and 26). Although not likely to operate from tactical theaters, the SAC mission is affected by what the rest of the Air Force does in developing an all-weather (low visibility) capability. Perhaps the best comparison is the B-58 and the F-101. These two aircraft seem both to have serious IFR landing limitations, and measurements indicate (references 81 and 82) that the flight

paths, approach speeds, threshold heights, and gradients are very similar.

Thus, the solutions of the ADC and TAC fighter IFR landing will probably be applicable to SAC. The B-52 and KC-135 landing trajectories are similar to the heavy commercial jet transports and considerable data has been and is being gathered on this matter (reference 23). The jet aircraft, whether it be bomber, fighter, or airlift in its design and application, requires new aiming points and flexible approach and flare trajectories not covered in any present standards (references 21, 22, 23, 26, 40, 68, and 69). No standards recognize that often 3000 to 4000 feet of forward flight are needed to reduce the sink rate from a 100-foot height.

Thus, the tactical guidance system should include in one of its modular forms a ground-based, flare guidance capability. Such equipments have had preliminary testing and seem reasonable to consider in a mobile design for rapid installation in remote areas (references 11, 29, 30, 31, 35, 56, 81, and 83).

As one views the total missions and aircraft of the Air Force, the full spectrum of today's flight equipment is involved, totaling perhaps 8000 to 10,000 aircraft. The trend toward other than nuclear war, with potentials of SEA and Korean type of hostilities on a global basis, emphasizes the need for full operational assurance of IFR landing at destination. Furthermore, the complexion of modern warfare is such that not to have the airlift, bomb or defense aircraft when needed can be catastrophic. Studies indicate that the immediate deployment of concentrated force by airlift can forestall much larger military actions. Inability to deploy often results in major conflicts and enormous costs (references 58 and 79).

Not only our railroads, but other methods of transportation as well have been minimized by the airplane. This has occurred to such a degree that greatly increased dependence on air transportation is now evident, and the responsibility of performing the needed function in "all-weather" is now greater than at any time since there is little else that can satisfy the current military strategy.

The thousands of helicopters (in excess of 5000) of the Army and perhaps 3000 aircraft of the Navy and Marines (in addition to those of the Air Force) bring the grand military total and mission capability on a global basis to a staggering amount. The major cost of this operation is justified on the basis of its being available when it is needed. Since timing on such

matters is always critical, these forces must be deployed and a tactical situation brought under control in a matter of days. Without a realistic all-weather capability, particularly the ability to descend into remote and foreign landing fields at night and in poor visibility, is tantamount to denying this major function. Unlike the airlines that fly routinely and the flight can be delayed, many Air Force missions are normally required within minutes or hours. This cannot be assured without the solution of the landing problems that were noted previously.

b. Size of Modules

The concept of a basic tactical landing system that has a "Signals-in-Space" standard should include man-pack units to be deployed for the bare strips in the forward battle area. Much larger equipment capable of satisfying the full flare-out and low-visibility requirements of a Navy jet transport (say the C-141 or C-5A) or a jet fighter (say the F-101 or F-105) at a more fully prepared strip (aluminum matting on sod) typifies the extremes in a modular system design. A correlation exists between the guidance demands, aircraft landing requirements, and electronic equipment size that appears to make this possible. The man-pack units may be in two modules weighing about 35 to 40 pounds each. The next modular step might be suitable for transport in a jeep or a small helicopter and have a weight totaling no more than 200 pounds. The most sophisticated module being a van-mounted system that can be airlifted (in a single C-130) to a bare strip (with mat perhaps) or an unequipped paved strip (there are thousands of these in the world). The latter module would be a microwave system capable of installation, flight inspection, and authorization (for full low-visibility use) in a matter of a few hours (still using only one C-130 with appropriate crew and installation staff).

The needs of the transport method are paramount in achieving this mobility. The standards of the airlift units (8 x 8 x 10 feet) should probably prevail (references 84 and 85). To have an odd-shaped module exceeding these dimensions means special handling and the likelihood that early deployment cannot be achieved. The standards seem to follow the "½" rule (4 x 8 feet); this implies that the next steps are 2 x 4 feet, and 2 x 2, and so forth. This permits the loading of the modules into the standard containers, aircraft, and follows the already established procedures of the airlift standards. For example, the top of a cargo area can sometimes take the ½ or ¼ basic dimensions (references 8, 10, and 12) so that the landing system would go into a strip with the initial flight without waiting for a special assembly at the site.

As discussed elsewhere, the beamwidths dictate the antenna size in wavelengths, and the frequency in turn dictates the size in feet. There is a direct relationship between the transport ability of a tactical landing system and its utility. A single C-130 could carry a major module system--say two major units and a number of minor units (man-pack) and then be utilized after delivery for the flight inspection of all the units. This could be achieved in a few hours prior to the arrival of the main body of the airlift. Similarly, a small helicopter may take an intermediate module to a forward strip from the main base of the C-130 (C-5A or C-141). These units are then freed of the transport need of large aircraft since flight inspection could be done just as readily by the helicopter. Advanced troops or "path-finders" with qualified technicians could man-pack the units to a remote helicopter site or certainly from the helicopter to a point (perhaps 100 feet removed) where the siting criteria dictates the location of units.

c. Accurate Delivery of Equipment and Supplies (Airdrop)

Reference 112 describes the current concepts of airdrop. It is obvious that with increased emphasis on global airlift for basic military deployment and support, direct delivery to the user by airborne means is also finding greatly increased emphasis. The families of airdrop techniques vary from the early World War II experience of dropping from 700 to 1500 feet of height to current techniques at 20 feet and less. The greater heights result in very poor accuracy of drop. Two prevailing conditions, winds above 15 knots and poor visual judgment, contribute to large drop errors. Drop zones for today's limited warfare concepts are greatly reduced in size and require close attention to many factors. Perhaps the most critical factors are:

1. The timely visual acquisition (in good VFR) of the target zone at low flight heights for alignment (references 113 and 114).
2. Obstacle hazards on the descent or at the 20-foot (or less) drop height of the new techniques.
3. Anticipation and execution of precise drop time (1 second may result in a 250-foot error).
4. Poor visibility and night operations.

Each of these suggests the need for a simplified alignment system which, in essence, is the tactical localizer (or a modular adaptation of it) that we have discussed for landing on a strip. The drop mission is often equivalent to an aborted landing and meets many of the same guidance criteria. Enemy fire

often forces the height of the flight down and results in poor aspect ratios of the drop zone or even its visual obscuration from a distance much in excess of a couple of miles.

Heap (reference 113) notes "atmospheric effects decrease the observed contrast as the object increases in distance from the observer, also the angular size diminishes until the object disappears in practice before reaching the laboratory (visual) threshold." The detection probability of the drop site relative to the navigation error is such as to make it quite difficult to locate, align, and drop at the right time to reasonable limits at normal speed. Over land, the problem is further complicated by the normal complexity of the ground pattern. These problems can be reduced to somewhat bearable tolerances with precise radio navigation aids that place the pilot close enough to the target that his probability of seeing it is adequately increased because his visual search angle is reduced.

Thus, the theoretical precision of the low altitude drop concepts such as the Ground Proximity Extraction System (GPES) and the Low Altitude Parachute Extraction System (LAPES) are not always realizable. The hazards and visual limitations should be considerably minimized with radio guidance. The vertical height is probably best measured by eye or with a precise radio altimeter, but the precise alignment, and anticipation of the imminence of the small drop zone could be improved with a precise DME from the drop point. The location of a man-pack unit for azimuthal guidance (localizer and multiplexed DME from the same point, with DME "off-set-zero" to the drop point) should greatly enhance this part of the operation. Little data on tests using such radio guidance exists and should probably be included in the flight-testing projects and in the photo measurements of typical drop missions (about five basic air drop techniques are under test--reference 112).

The clearance over obstacles to arrive at the low 20-foot height might employ a small vertical guidance unit (similar to a glide path). This might be situated ahead of the drop zone (see Figures 38 and 39) so that the descent for the flat, low run (about 2000 feet) for extraction and climb can be safely executed. The use of the DME at the localizer could also provide this clearance function: the pilot maintaining a safe obstacle clearance (precision radio altimeter) until a given distance from the drop zone (as determined by the ground crew), before the very low pass for extraction or drop. These drop techniques also provide a possible means for delivering a guidance system for use on subsequent missions. For example, a daylight drop of the radio guidance could assure a safe back-out operation or low-visibility operation for that or other aircraft not familiar with the drop zone.

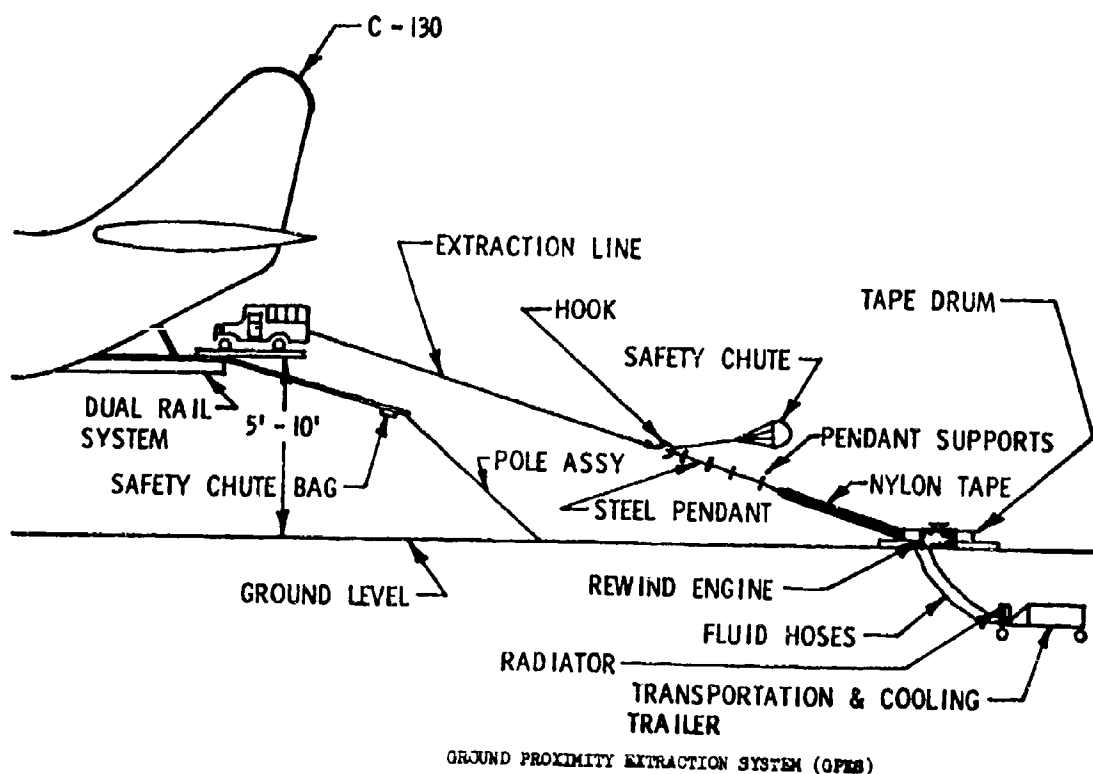
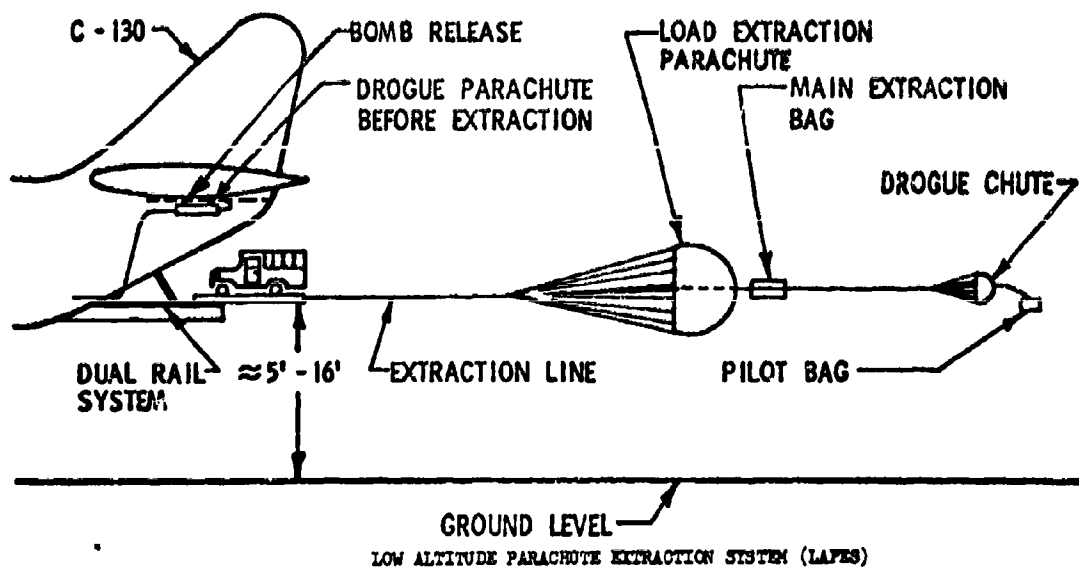


FIGURE 38. LOW-ALTITUDE PARACHUTE EXTRACTION SYSTEM (LAPES) AND GROUND PROXIMITY EXTRACTION SYSTEM (GPES)

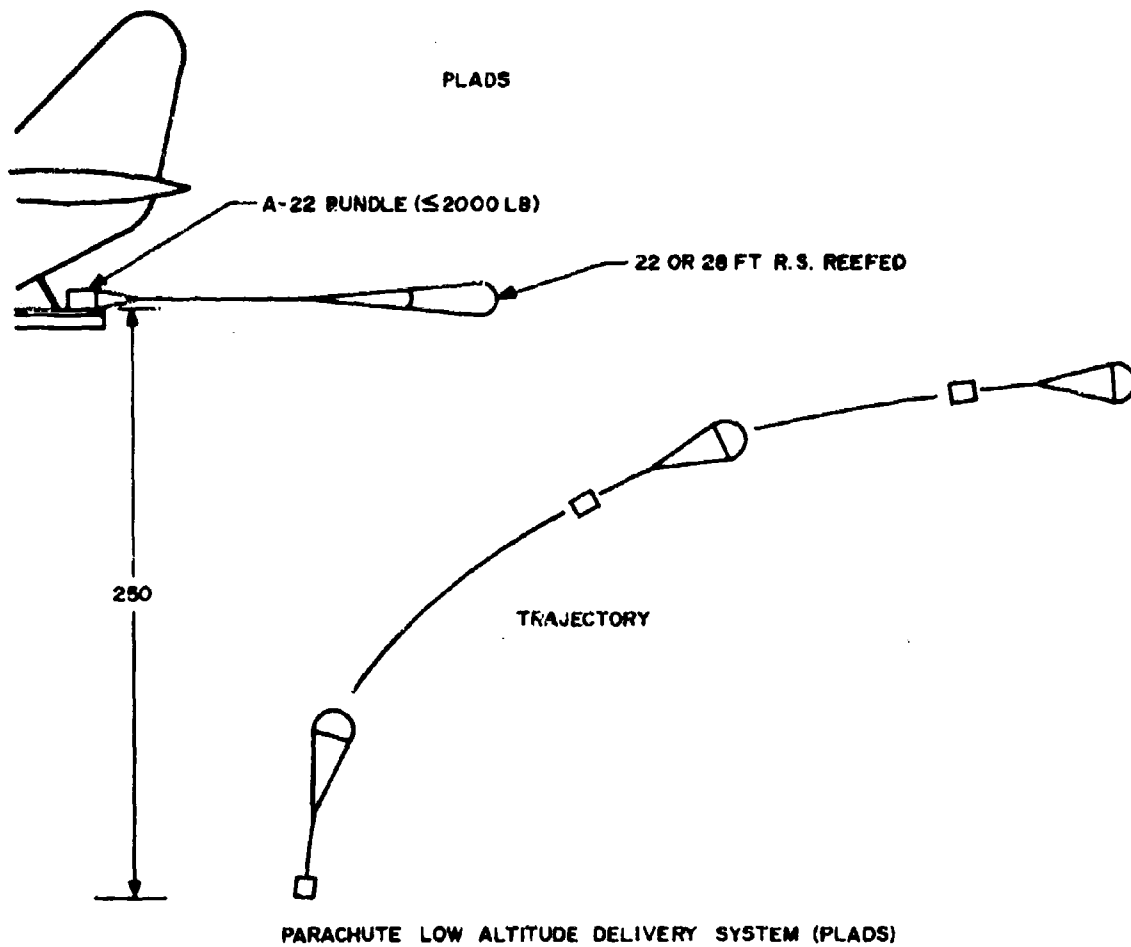
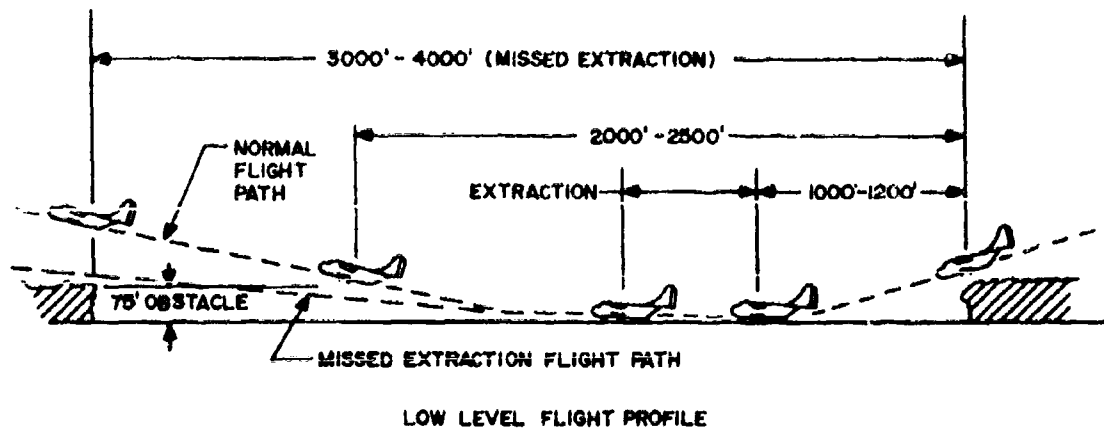


FIGURE 39. LOW-LEVEL FLIGHT PROFILE AND PARACHUTE LOW-ALTITUDE DELIVERY SYSTEM (PLADS)

3. STEP II--FLIGHT AND TECHNICAL REQUIREMENTS FOR A TACTICAL LANDING SYSTEM

The missions determining the operational needs must now be further defined with measured quantities. Quantitative descriptions of approach and landing flight profiles, instrumentation needs and obstacle clearances are essential. One valued means of accomplishing this is with the photo-measurement techniques under various conditions for various aircraft. A WADC report (reference 36) describes one possible technique that clearly portrayed the long 4000-foot path (from 100 feet) of the jet fighter. Similar data for the jumbo jets C-141, C-130, COIN, V/STOL, utility aircraft, and helicopters are needed. The KC-135 is similar to the civil jet (707) and considerable data is available on this system.

The airdrop mission may call for precision azimuthal alignment, yet no landing per se is conducted. The presumption that this mission can be flown on instruments and the sensitivities near the radiation source (angular convergence) should be examined. The range to a drop point may also be important and the constant-altitude flight may not need a glide slope as such.

The Pi-Fax program has much to offer in the way of inputs to the Air Force landing project, but should be extended to include basic guidance and testing a greater variety of currently operational aircraft. It is difficult, for example, to test realistically a landing system for a jet fighter, as to its tactical field suitability, with only a two-engine piston transport. Data on the electronics and guidance signals is available by such means, but the marriage between the elements of mission, speed, instruments, and guidance is not achieved and, in fact, misleading conclusions can result from not testing the actual interrelationships. For example, it is likely that all current GPIP locations are incorrect for current aircraft. Varied but typical missions with perhaps two different jet fighters (involving minimum tactical field lengths and poor obstacle lines) should be examined by actual flight testing. Photo-recordings of approach gradients, flare points, and desired approach aiming points, would be established. A detailed discussion on landing measurements indicates some of the critical dimensions of an approach and flare system.

Even if flare guidance is not provided, the approach guidance must be used safely to include a visual flare. At night and with minimal approach lights, excellent azimuthal guidance may be far more necessary for tactical runway center-line alignment than at fully equipped bases. Similarly with

minimal lights, the vertical guidance may also be far more dependent on the radio guidance than in a civil field or a fully instrumented and lighted main base. Tactical operations may not permit the 3000-foot of approach lights normally used. No detailed measured data exists of a wide spectrum of the Air Force type aircraft, for ability to correct vertical and horizontal alignment errors near the ground without these visual aids. The operations of large tactical aircraft, such as the C-5A, are critical since they are planned to operate in short fields with enormous weights. As soon as this type aircraft is in flight test, the typical landing profile should be determined in great detail (response, side step limits, flare length, etc.), so that quantitative guidance criteria can be established.

It is surprising that the aviation community, and the jet aircraft in particular, have come so far without accurately recorded data. The FAA only recently instituted an IFR landing measurements program to be completed late in calendar 1967. The variations of jet transport aircraft landing parameters (about 12 quantities) in IFR, at several locations will be determined. CAT II and III operations will have better guidelines. The much wider spectrum of speed, size, numbers, and weights of Air Force aircraft would suggest a project similar in nature to be started soon. The misleading ICAO standards (reference 26) do not take into account the aiming point, flare height, threshold height, flare distances, etc. (references 23, 65, and 92), already identified in the FAA (Geoffrian) and Air Force (WADC) reports. Neither report is detailed enough nor does it provide sufficient samples to extrapolate. The already evident discrepancies, however, are so great that without a major rewrite of standards, a completely unsatisfactory tactical landing system could evolve that would not see final field use. The landing distance criteria (descending over a point 50 feet above the surface and then coming to a stop) is unrealistic for determination of runway length for current jet aircraft. Furthermore, this certification of landing distance is not done with the constraints of a specific landing point, and realistic threshold clearance has not been employed by the aeronautical certification authorities. Consequently, the flight research program should quickly establish a new set of landing characteristics for IFR.

During an IFR landing, the effect of winds, turbulence, and wakes of preceding aircraft lead to a need for re-establishing the desired and safe approach to flare path. A jet fighter crossing the threshold at about 8 feet at a speed of about 175 knots is quite a different problem than a STOL at 8 to 10 degrees approaching a short strip at 40 to 50 knots. Each has its place and should have a common means of landing (flexibility of path and sensitivity) to avoid the development of several incompatible solutions to the Air Force's landing problems. The temptation

to solve various problems and missions with separate landing systems must be avoided. It is the easier way out, but costly and ultimately much more complex when the overlapped missions, inventory, training, etc., aspects are evaluated.

Simulation is an aid in low-visibility work and has certain potentials. However, in the very low visibility work, misleading information is possible when simulating the tactical landing environment. Lights will be nearly non-existent, except hopefully for a vertical guidance such as the simple "meat ball." The actual testing in low visibility with the Air Force aircraft of several types would be possible at the Arcata testing station (Landing Aids Experimental Station) established for these purposes. It is well instrumented by the Bureau of Standards for precise visibility measurements. An important and a long history of weather exists for this airport, so that the probability of encountering low visibility weather is well established.

It would appear from this history that about 100 days per year would have fog conditions. Furthermore, there are times of the year when extremely low visibility exists. For example, there are 84 occurrences in a typical December with less than a 100-foot ceiling and 98 with less than a $\frac{1}{2}$ -mile of visibility. The simulation of a tactical landing with the aircraft under consideration, flying a typical obstacle line without visual aids in low overcast has not been done. At this point in landing system history, the fine details of the problem area are now the important aspects that are not possible to simulate with an electronic simulator in a laboratory, with another type of aircraft, or in good weather with various types of "hooded" approaches. Furthermore, there is much to say for having pilots (who may have volunteered) but who are willing to face the actual risk that exists in such testing. If we are to ask the operational pilot in a strange tactical landing environment to do it, certainly we must have quantitative data derived from many actual landings in similar low visibility.

The parallel can be drawn to the aircraft that is built and ground-tested but never flown. How can the actual "feedback" be obtained without the actual, real flight test? Statistically significant live flight testing is necessary to arrive at the best combination of aircraft instrumentation, flight path angles, sensitivities, aiming points, etc., and interrelationship of which do not now exist in a useful engineering form. The designer of tactical landing systems or tactical aircraft or the Field Commander who may commit his air action under such conditions do not have this essential data.

What is the minimum lighting possible? How dependent is the pilot on the localizer and glide slope at the lower heights without lights where he now normally abandons the radio in favor of lights (reference 115)? What are the effects of course convergence with different siting criteria for the guidance? What coverage and accuracy of DME data is needed?

The actual application of the current extensive knowledge of aircraft instrumentation and flight control to fully flight-simulated conditions with the landing system modules should then permit the modular concept to evolve from experience. In one case (say a COIN type aircraft) no flare is needed, and a straight glide slope to ground impact is possible. In another, say the heavy airlift aircraft, some flaring is needed (5:1 sink rate reduction) merely to avoid breaking through the surface or forcing the landing gear too hard. The difference between a ground impact load of 2 fps vs 10 fps is about 25 times, since one is dealing with energy in the vertical plane and the V^2 of the sink speed must be realistically established for each aircraft. This, in turn, dictates guidance and instrumentation criteria.

Considerable testing has been done that has never been correlated in a common report and the knowledge gained has never been catalogued. NASA has reported engineering data on jet, helicopter (references 100 and 104) and V/STOL landing aircraft (such as the Breguet 941). The FAA has similar reports on the ADCOLE helicopter tests (references 101 and 102), many tests with Flarescan, Regal, AILS, GCA, etc. Foreign governments, particularly the CEV of France, BFS of Germany, and the BLEU of England have completed much work. Experience in the Air Force is also large with FI-FAX data, early all-weather experiments with various microwave tactical systems, etc. The IATA, airlines, Navy and Marines are other sources. Most of the data is not in terms that would be meaningful here, but nevertheless some guidelines on sink rate, aim points, terminal touchdown conditions, desired and possible glide angles, etc., does exist, but has never been correlated. One BLEU report indicated large differences in "Approach Success" under given RVR conditions for a jet and a piston aircraft. The flight testing would use such information more as a guideline for methods of measurement, expected noise level (tactically important), and handling properties.

The major effort in Step II of the Synthesis is to assure that the operational needs are not just transferred by a staff engineer into what he thinks are system specifications. There is often the temptation to overlook this step which is essentially operational research into a difficult, hazardous,

and demanding area. WADC (Patterson) and the M-FAX programs at the IPIC school are predecessors to what should be a greatly expanded effort in the synthesis process of arriving at critical decisions such as radio frequency, beamwidths, modulation, coverage, accuracy, etc., that will permit the developments around a "Signals-in-Space" standard. Any attempt to write this national standard without some thought to even the best radio frequency (as now seems the case) is like trying to design an aircraft and then selecting an engine by random process. It must be matched to the rest of the aircraft, its desired performance, ceiling, speeds, etc.

The many trade-offs of the various choices of radio frequency can only be realistically established by data which, in turn, is based on the flight testing. In the flight test, several existing equipments may be tested to determine certain parameters (or perhaps what might be eliminated), so that some interrelationships are established between the radio frequency, flight parameters, and pilot instruments. This is essential for the considerations in Step III--the synthesis of a Tactical Landing System. Such matters as realistically studying the 1/10 or 1/8 clearance criteria (references 107, 108, and 111) for V/STOL, STOL, and helicopters may indicate that paths as high as 10 degrees elevation angle are minimal in many sites to allow for obstacles (up to 6 to 7 degrees) clearance of 1 to 2 degrees, and a linear (below path) course deviation indication in the cockpit (perhaps another 2 to 3 degrees).

These criteria are definable according to at least a skeleton of standards developed by the ICAO that could be rewritten and expanded for the tactical landing concepts. The ICAO standards are voluminous, and are for what is relatively a much simpler problem (references 2, 3, 4, 21, 26, 68, 69, and 70). The many quantitative ICAO definitions of a landing need redevelopment to bring out the realities of the jet aircraft. Its curved path near the ground (whose guidance may have to be created electronically, since lighting will be minimal and low visibility is desired). COIN (reference 78), STOL, and helicopter aircraft do not at present have any equivalent set of standards as does the fixed-wing conventional aircraft.

Much of the large ICAO documentation relates to slower propeller aircraft flying with excellent clearance over obstacles that result in paths of 2 to 3 degrees (not the 3 to 10 degrees that may be involved in difficult tactical sites with the 1/10 clearance criteria). The ICAO would serve as a check list in this operation development of the tactical landing system concepts. Some twenty years of extensive effort

has evolved the ICAC standards and, though lagging in application to current technology, they would stand as guidelines and could be updated for military Air Force missions and aircraft.

A large symposium would probably aid in airing the flight technical requirements of tactical landing. The AIAA and similar professional groups often are willing to sponsor such a symposium. It has the advantage of providing inputs to the Air Force and other military users on tactical landing requirements (each Command's views would be interesting), and as a signal to industry that the Air Force was taking the matter more seriously, with increased emphasis and improved engineering planning. This would call for some guidelines being expressed by the upper technical echelons of the Air Force and DOD to indicate that industry aid was sought, but under Air Force guidelines, and that, as the program evolved, there would be many aspects of the modular systems that fitted the "Signals-in-Space" concepts that could be built. With air and ground division, precise flareout, man-pack, etc., there would be at least 6 readily identified areas for industry participation. Only after the standards of color TV were bitterly established, did the industry invest the effort to bring it into reality. Until then it was a laboratory novelty (references 70 and 71).

a. Airborne Needs Affecting Ground Guidance Criteria

One often has a wide choice of guidance techniques that could supply signals in space for approach and landing and air drop operations. This is already evident as was noted in the review of the many past and present systems. Those aspects of the airborne instrumentation and piloting and flight control problems that affect the choice of a ground radiated, tactical landing signal are:

1. Airborne displays (meter, cathode ray, electromechanical).
2. Sampling rates (delay between displacement and signal to controls).
3. Accuracy and stability (displays often sense very minute errors or "wiggles").
4. Automatic and/or manual flight control response to undesired guidance perturbations.
5. Indication of obstacle clearance (markers, altimeter, glide slope).
6. Indication of height, range, and azimuth. Means of integrating (6) into a computed complex flight path.

7. Visual, aural, and physical guidance cues to pilot.
8. Flight path geometry (curved, straight path, selectable angles and sensitivity).

We shall discuss each of the aforementioned topics (1 through 8).

1. A ground radar, for example, cannot activate airborne displays such as flight directors with their electromechanical or meter movements, without very complex ground environmental equipment, training circuits, data links, etc. Two complex examples were the AGCA work in the Air Force and the SPN-10 of the Navy. Both have been made to work; however, the simplicity requirements of a tactical system are violated. A simple, direct, ground beam signal to the aircraft receiver can activate the currently developed displays. A great variety of such displays have been developed and are relatively more advanced than the guidance that activates them. This is true because research and development on displays can proceed by simulation (references 46, 51, 52, and 116) without cooperative aspects. Radio landing guidance is very demanding of cooperative design of both air and ground equipments. Whereas a special airborne instrument can be used without reference to anything but what is in the aircraft, a cooperative ground guidance system must be common and cooperative with widely installed ground electronics.

2. The sampling rates are important. Most instrumentation and flight control studies have indicated that a three to seven fresh samples per second rate is adequate (delays of 0.25 to 0.60 second with two-sample smoothing). Certainly, any delay in excess of about 2 seconds in deviation response is detrimental to good landing guidance (Section 5.2 of reference 51). The GCA delay is another example. With excellent training and teamwork, the delays can be kept low, particularly with controller, pilot anticipatory effort. However, this delay is never better than a beam guidance signal such as an ILS, which has a much lower and more consistent delay than the best GCA. Poor GCA coordination can create delays of several seconds. In some tactical operations somewhat lower sampling rates are imposed by some suggested techniques. Another example is an airborne radar with a scanning antenna, where poorly defined samples a few seconds apart, are often involved.

Time-sharing of the azimuth and vertical guidance of a beam system is another example. A common ground transmitter and a single airborne receiver might time-share three functions (vertical, azimuth, and DME guidance) in light-weight airborne and ground units. In some cases the lower sampling rate may limit the ability to have a high rate-of-change of path (such as a flare or close localizer turn-on) where a steady-state condition does not exist. Some studies and flight tests are

probably in order to arrive at a quantitative relationship between sampling rates and the other display requirements. Sometimes the airborne display has damping and its own response time or rate indication so that this imposes some requirements on the ground beam formation units. "Quickening" or "rate-aided" displays are useful with a steady-state guidance. Non-linearity, beam bends, flat spots, etc., of a landing guidance signal destroy much of this instrument utility since false beam rates are introduced.

3. The human "coupling" to a visual cue can be more precise and responsive than is often thought possible. (reference 117 suggests that a professional ball player may physiologically "couple" to a thrown ball with delays measured only in hundreds of seconds. The ILS-ICAO standards call for a full-scale pilot deviation indication of ± 350 feet at touchdown (representing ± 2 to 3 degrees). The typical runway is only ± 75 feet wide (sometimes perhaps tactically ± 50 feet) and, to avoid running off the edge, course alignment is controlled to about ± 20 feet of centerline. This represents a deviation error of less than $20/350$ or about 5 percent ($1/20$) of full-scale cockpit indication. This is a needle movement of only about 3 percent of the total IATA deviation display when considering the total (\pm) display of deviation error. Remember the display of runway edge is only 10 percent of total course width.

On a 3-inch display, a deflection of only about 0.10 inch must be followed by the pilot to achieve successful landing for Cat III. Needle wiggle due to errors, reflections, moving objects near the ground station, are all discernible to the pilot even if they are only equivalent to something like 0.1 to 0.2 degree.

The pilot often uses rate-of-change of deviation (or a computer aids him) and, of course, a few hundredths of a degree per second can be quite common in bracketing and aligning azimuth. The radio transmission must radiate with great fidelity the desired course to the aircraft. Included in the fidelity of transmission is the ground antenna, its alignment, the radio propagation path, aircraft antenna, receiver, decoder and display. The human instrumentation capability that exists cannot be used with unstable displays caused by transmission degradations. False deviation indications due to reflections, side lobes or course bends, etc., derogate the display system extensively.

Thus, even in a tactical environment the beam accuracy, stability, etc., is as important to the airborne displays as a fixed system and should be designed for this function. The three-dimensional indication of flight path to a specific landing point is probably the most demanding of all display/radio guidance combinations because of the high risk entailed in IFR and night operations.

4. In manual or automatic flight control, the airborne requirement imposed on the beams in space is rather high. As noted above, the activation of displays with even a 0.1-degree displacement error is common and rates of a few hundredths of degrees per minute are important. When coupled automatically, the response is not tempered by human judgment and all errors due to beam transmission characteristics are followed with minimum delay. A moving vehicle in front of the ground system may deflect the beam which, in turn, is received in the aircraft and the autopilot immediately responds by turning the aircraft toward the erroneous indication. When the disturbance is removed from the beam signal, the aircraft is again turned immediately back to the correct course. For precise fixing, "tight" coupling is needed and bank angle limits are helpful, but the automatic IIS flight mode is probably the most demanding of a beam system, since an automatic pilot can respond "blindly" without human judgment. Often, pilots vary their response times to coupling tightness upon recognizing false beam disturbances displayed on the Flight Director and are thus more adaptive to such matters.

This airborne requirement placed on landing guidance systems can be satisfied by proper selection of frequency; this, in turn, determines beam accuracy and immunity from the adverse affects noted above. Beam scanning, lobing or switching can also have an important effect on this criteria for landing beam guidance quality and fidelity.

5. An indication of the safe descent path to clear obstacles in a tactical environment particularly bare, forward, and rapidly prepared landing strips (where all the excellent clearances of fixed bases cannot be adhered to) is essential to safety. The airborne display of adequate clearance beneath the descent path is essential. Such features as full-scale fly-up, total linear deviation indication range, and perhaps the addition of a beam signal (readily achieved in microwave systems) that positively assure the pilot his aircraft is not below the obstacle clearance line may also be required. A 1/50 obstacle slope line from threshold common in civil fields (references 118 and 68) or large military fields, may give way to 1/30 1/20, or even 1/10 for STOL, VSTOL, or helicopters (references 104, 105, and 111). Thus, obstacles at 2, 3, and 6 degrees must be considered.

Typically, the higher the obstacle clearance criteria, the more readily a site can be used for tactical landing or air drop. The ratio between, say a 1/50 criteria and a 1/10 criteria for obstacles on the descent path (glide slope) could make a

difference of perhaps 20 to 1 in the number of tactically available landing sites. A military Commander is nowadays much more dependent on air support of all types and, to retain flexibility in the battle areas, must have as much latitude as possible to determine that the air support or weaponry is where and when he needs it. Making available many times the present potential tactical sites for helicopter, airlift, STOL (or COIN) aircraft could readily justify the entire TACLAND project. A study is suggested of a typical, foreign, tactical environment, such as SEA (hilly regions) as to the number of sites possible with, say five, different obstacle criteria lines. This criterion, in turn, is a factor of that direct effect on cockpit displays used at various vertical angles (most aircraft will fly at steep angles). Cockpit instruments for selection of angle, sensitivity, and deviation clearance are related to the guidance capability.

6. The indication of height, range, and centerline of the intended landing point is commonplace. Often these are integrated into a flight display, but the "raw" data is still usually available to the pilot for monitoring or in case of failure of the integrated display system. The airborne requirements imposed here on the ground guidance are that it be in a form that can be monitored in its separate elements in the air and that display integration is easily accomplished. Mixing, say, an airborne radar output with a vertical ground-radiated glide slope, is possible in the displays, but certainly much more complicated because of the airborne data processing of two diverse units. The airborne data processing of the DME, azimuth and vertical signals in a common processor circuit has obvious advantages (FAA-AILS is an example). This permits one airborne receiver and processor to handle the three or more inputs that often require up to 4 airborne units and separate processors. Thus, the display system is normally activated from a means that is similar electrically for the three positioning and guidance signals and this, in turn, is imposed as a desired objective on the ground signals (beams, modulation, and time-sharing techniques).

7. Pilot cockpit display systems are usually visual, though some aural signals are used (markers, radio calls, station identification, etc.). The airborne visual and aural pilot inputs are well established (reference 37) and are probably not going to be changed for a tactical landing system. Thus, guidance schemes with widely divergent displays, aural signals, complicated data links, etc., are not likely to succeed in the tactical environment. The guidance signal offering of ground imminence a few seconds prior to touchdown by aural and visual means should be implemented to avoid a chance violation of the obstacle lines. The ground beams would radiate signals for these critical warnings that would fit into the current display and aural concepts of the cockpit.

8. The flight path of a helicopter varies enormously from that of a jet fighter, both of which are tactical aircraft used by the Air Force. Displays in each machine do not differ much. Looking at the instrument panel of an F-101 and that of a V-107 (CH-46) does not demonstrate the great difference in the approach and landing guidance requirements of the two vehicles. It may be that some innovation of instrumentation will develop after an advanced but simple tactical landing guidance system evolves. At present, however, the flexible guidance signals must be able to satisfy the somewhat common instrumentation in diverse aircraft having varied approach speeds (190 knots to 30 knots) and glide angles of 2 to 30 degrees. The radio guidance system that will evolve from the synthesis outlined here should offer this flexibility by a common "Signals-in-Space" standard. Different ground modules for different flight trajectories and sites will be part of the standard, but the interpretation of these guidance signals is likely to be with the cockpit displays and control equipments now existing or in development.

This places some constraints (not serious) on the guidance signals. Selectable angles and sensitivity, curved paths, etc. (for various environments and aircraft configurations) will be displayed to the pilot, but must be safely generated by the ground units relative to the exact, specific, landing point. Thus, the aircraft characteristics and their instrumentation to fly the desired approach (flare) paths will impose another airborne requirement on the design of the tactical landing system.

- b. Low-Visibility Landing Requirements That The Combined Ground Guidance and Airborne Displays Must Satisfy
 - 1. Appropriate approach sink rate (sometimes a precise 5:1 reduction in the clearing of obstacles--at just the right point).
 - 2. Correct aiming point for approach (mv^2 of aircraft--reference 93).
 - 3. Correct indication for flare initiate (IFR and black-out).
 - 4. Touchdown (or flare) aiming point.
 - 5. Touchdown sink rate (termination of vertical and horizontal guidance speed reductions, but above stall).
 - 6. Horizontal deviation within limits (sensitivity of deviation indication).

7. Nearly flat attitude in roll near ground (for large aircraft).
8. Heading correct for wind to retain low deviation on approach.
9. Heading or aim point correction near ground for wind shear (prior to or in flare).
10. Heading "de-crab" just prior to touchdown (relative to main gear touchdown--not too early or the aircraft will be blown off alignment and not too late or it will result in side thrust on the gear).
11. Heading and displacement held within limits for roll-out.
12. Abort procedures for inadequate solution to any one of steps 1 through 11 above.

4. STEP III--CHOICE OF RADIO FREQUENCY

Many of the results of Steps I and II will now be significant. For example, as shown in the landing measurements discussion, some aircraft have extremely low elevation angles as seen from the touchdown point during the terminal 2 miles of flight (from 0.30 to almost 3.0 or 10/1 for the F-101). Yet other aircraft use steep angles without variations until just prior to contact when a small flare is initiated about 100 to 200 feet (less than 50 feet of height) from touchdown (V-107 and Breguet 941). For some aircraft such as a carrier fighter or a shore operation into cable arresting systems (SATS) the flight path is straight even to contact, the gear being designed to take the impact. This wide variation is described in detail in the section on flight measurements.

The point to be made here is that a common military tactical system (merely to be common in the Air Force) must have the radio transmission characteristics that permit formation of guidance beams or signals over this wide range. Gilfillan, AIL, Sperry, Hughes, LFE, Tridea, Bell and others who have studied the long flat flare problem often conclude that a beam about 0.50 degree in the vertical dimension is necessary. In fact several systems use this beamwidth, GCA/PAR, GSN-5, SPN-10, REGAL, FLARESCAN, AILS, etc. On the other hand, where a long flare is not needed a beam much wider may be acceptable. This is the real problem in the establishment of a useful "Signals-in-Space" standard. If a lower frequency is picked (around 1000 Mc or lower), antenna aperture sizes that control the

radiated energy become enormous for 0.50-degree beams. If one relies on earth reflections such as the (FAA/ICAO) 330-Mc glide path, tactical flexibility is denied and growth potential is restricted. (Even the FAA is now considering a ground microwave radiation, that is converted to a 330-Mc signal in the aircraft.)

If one then uses the argument that, since we are looking for a man-portable landing system, the upper end of the useful microwave spectrum (around 35-70 kMc) is the best, other serious problems evolve. The transmission of microwaves through the atmosphere (in all its various forms including heavy rain) becomes restricted because of absorption and backscattering. Even at 24 and 36 kMc, where some experience exists (and considerable propagation data) a power increase of several times is needed (reference 109). For a typical 20-mile (maximum) path, the following table (approximately) illustrates this point. (See Volume 13, Radiation Laboratory Service.)

	<u>15 kMc</u>	<u>24 kMc</u>	<u>36 kMc</u>
20-mile free space	20 Watts	40-50 Watts	90-100 Watts
with rain	150-200 Watts	2000-3000 Watts	1-2 Megawatts

The antenna size for a $\frac{1}{2}$ -degree beam and a 2 degree beam illustrates the desire to go as high as atmospheric and weather absorption permit (all dimensions in approximate feet).

	<u>1 kMc</u>	<u>3 kMc</u>	<u>5 kMc</u>	<u>10 kMc</u>	<u>16 kMc</u>	<u>25 kMc</u>	<u>36 kMc</u>
$\frac{1}{2}$ degree	120	40	24	12	8	5	4
2 degrees	30	10	6	3	2	1	1

Figures 40 through 43 illustrate the above points in more detail.

Assuming an airlift capability of the narrow beam system to accommodate jet landings ($\frac{1}{2}$ -degree antenna), the outside dimensions should be kept below 10 feet for direct loading into most aircraft. To avoid disassembly of critical items such as the antenna, the 15 to 16 kMc region and above is desired.

For a man-pack unit where the largest dimension might be limited to 2 feet without disassembly, again the 15 to 16 kMc region and higher appears attractive. The commonality argument, now linked with the size, and weather absorption leads one to the region of 15 to 16 kMc.

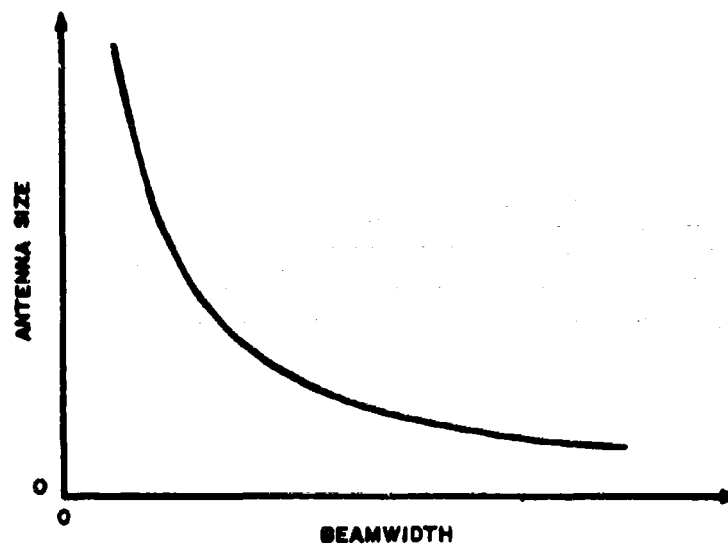
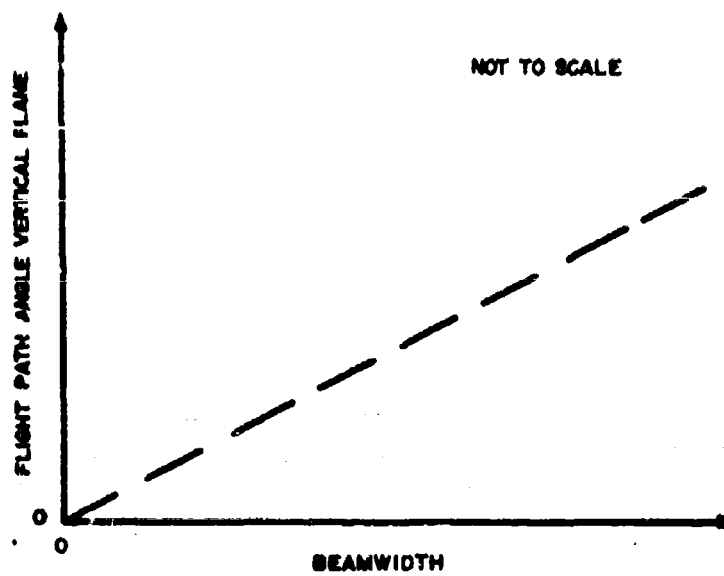


FIGURE 40. RELATIONSHIP OF BEAMWIDTH TO PRACTICAL GLIDE ANGLES

NOT TO SCALE

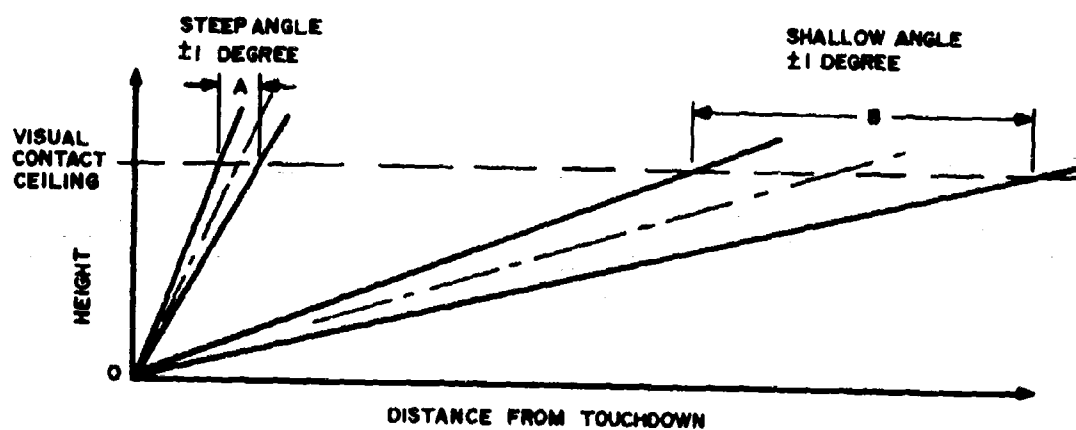
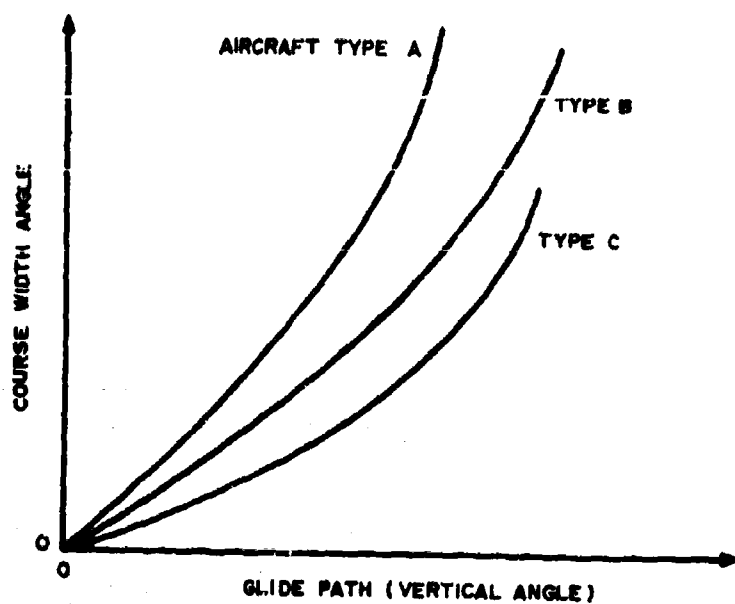


FIGURE 41. COURSE WIDTH VS: VERTICAL ANGLE

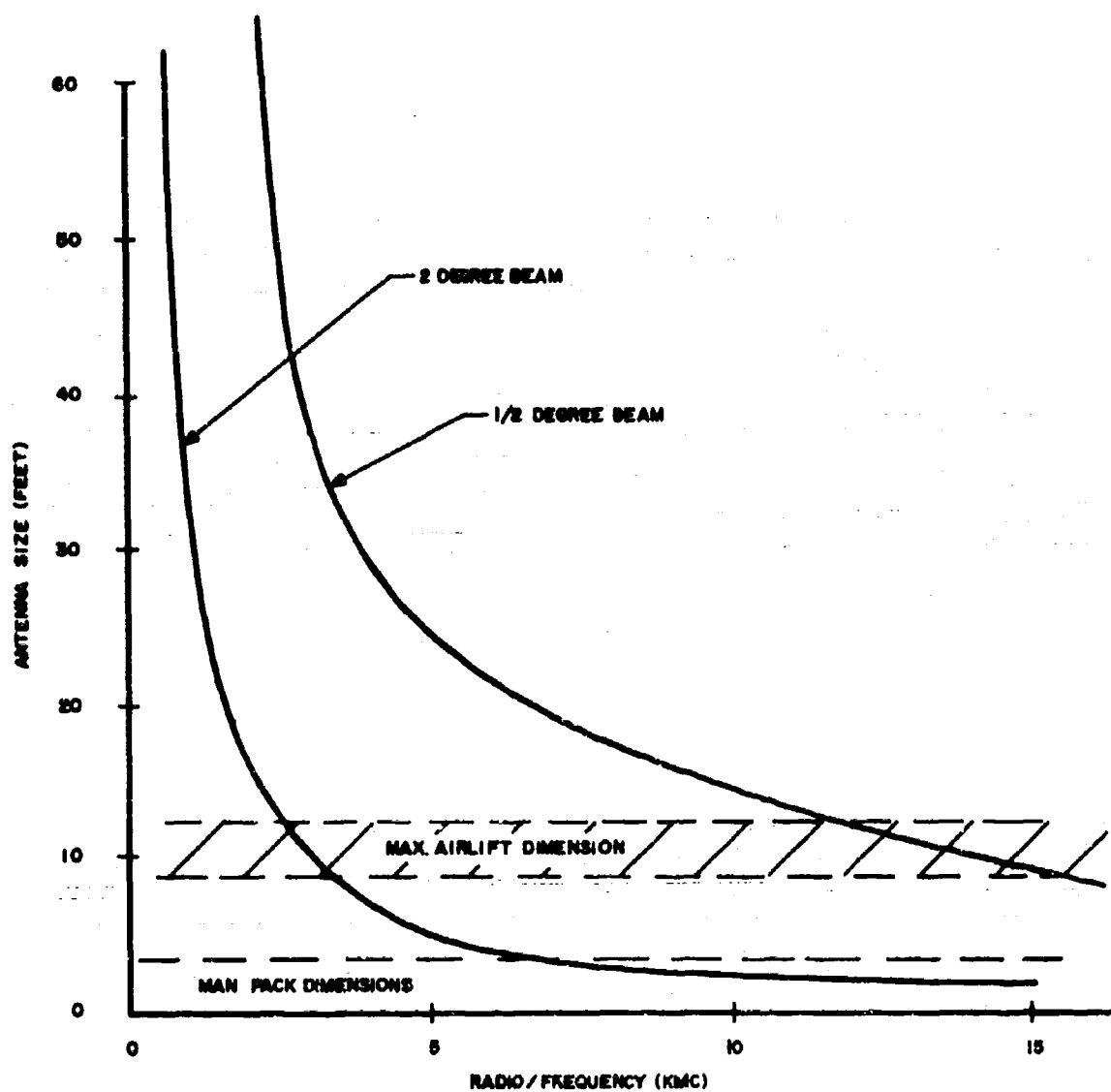


FIGURE 42. ANTENNA SIZES (APPROXIMATE) FOR GIVEN BEAMWIDTH

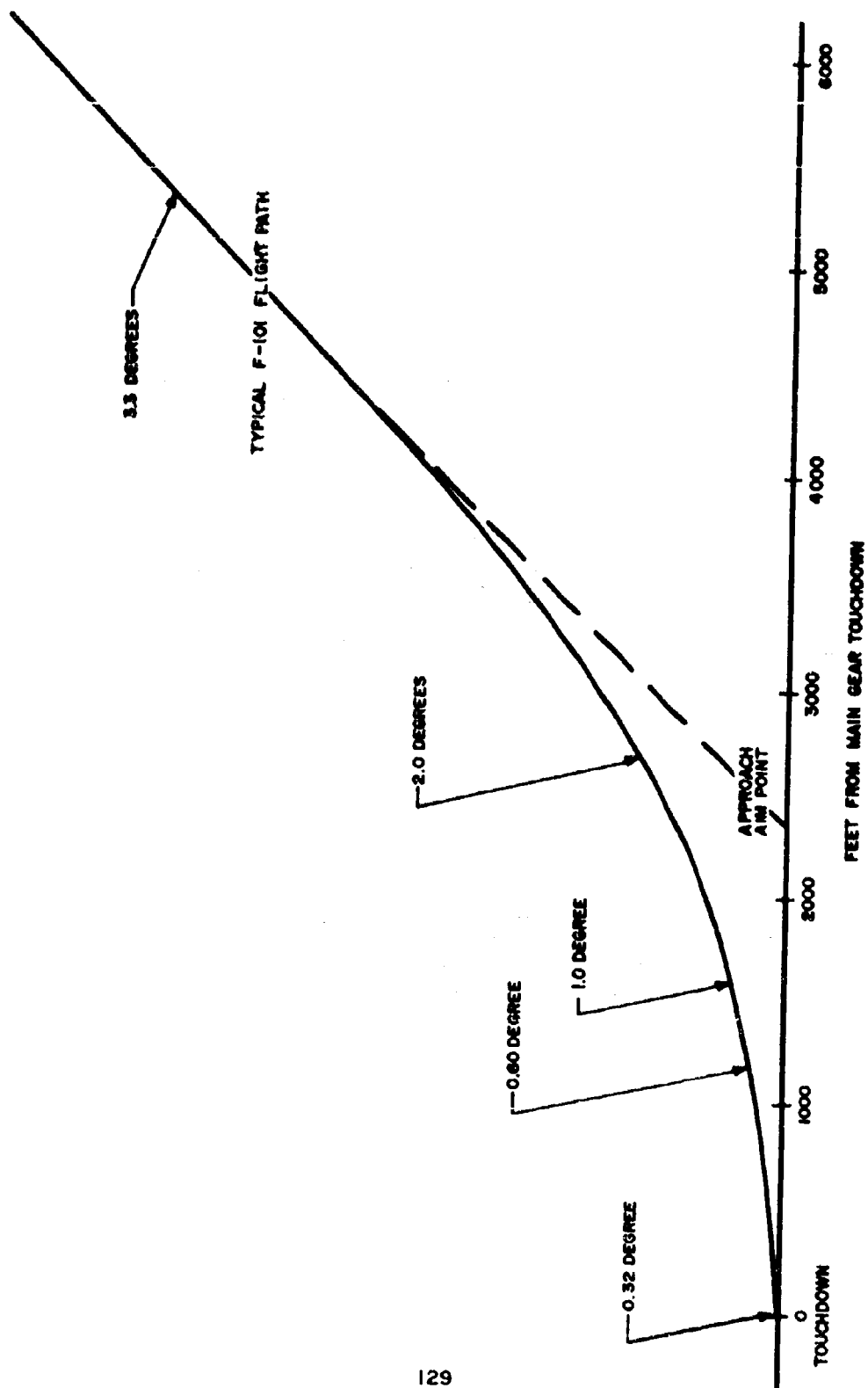


FIGURE 43. FLIGHT PATH ANGLES DURING FLARE-OUT OF A FIGHTER

10 kMc (X-band) is not considered favorable (even though antenna sizes are attractive) for the following reasons. It is an overly populated band with dozens of radars, and extensive interference is probable. No clear frequency assignment (channelization scheme) from the FCC or the military counterpart on an international basis is likely. It is further interesting to note that the industry and government test programs have also concentrated at 15 to 16 kMc (TALAR, FLARESCAN, AILS, SPN-41, etc.) for some of the above reasons.

The SPN-41, for example, uses an antenna about 2 feet in dimension mounted in a two-axis stabilized platform for projecting a fixed guidance signal from a rolling and pitching ship. The stabilization of a large antenna also limits the Navy's choice in this matter. In fact, the Navy SPN-10 utilizes 36 kMc for some of the same reasons. It does not function for (radar-data link) guidance control, however, beyond about 4 miles, because of the propagation limitation (backscatter, rain, absorption) noted previously. The SPN-41 is consequently under test for the extended "feed" for this system--from about 20 miles (reference 87).

The modular system concept must consider not only the choice of frequency from the viewpoints of propagation and available channel assignments, but also from the viewpoint that the physical packaging is such as to assure portability and transportability. Perhaps four basic sizes should be used--just as standards are now being developed for the individual pallet size for cargo aircraft, so also must similar standards be developed for packaging the various versions of a tactical landing system. Since the basic size in airlift cargo is 8 x 8 x 10 feet and a "half size" container is 4 x 8 x 10 feet, the height dimensions seem to run in $\frac{1}{2}$ multiples of 8 feet. (Diagonals of 8 x 8 feet would be about 11 feet.) This would make antenna sizes of 2, 4, 6, and 8 feet attractive so that the antenna would be mounted in the equipment without need for any reassembling of such a delicate and complex unit at the site. Time delay, training, potential damage, loss, and installation errors, can be avoided by a fully "integrated" design and shipment. This would permit a cargo aircraft such as the C-130 to deliver a complete system ready for operation when unloaded from the aircraft and properly positioned. Assembly from numerous containers with the inevitable missing element should be avoided. With such dimensional concepts, the 8-foot maximum dimension seems to be a good compromise. This would generate a $\frac{1}{2}$ -degree beam for the guidance path of the heavy jets (transports and fighters), and the next model size (4 feet) would be for approach-only capability (equivalent to standard ICAO-ILS) with appropriate beams, and the third model size (2 feet) would be for the small antenna for large vertical angles, no flare, etc., such as COIN, STOL, and helicopters would use.

a. Frequency Approvals

The FCC, ITU, and other national and international frequency allocation bodies have increasing demands for radio channel assignment for hundreds of purposes. It is unlikely that any new radio frequency band will be opened for Tactical Landing unless it is shown conclusively that it is completely impossible to operate in one of the bands already established. There are only two clearly specified assignments in the FCC "Rules and Regulations" (reference 87).

"Part 87, Aviation Services, sub-part 'N,' Radio Navigation Land Stations" of the regulations list ground stations that are "directly associated with airborne electronic aids to air navigation" only in the following bands.

960--1215 Mc (TACAN-VORTAC)
1535--1660 Mc
5000--5250 Mc
15400--15700 Mc
24250--25250 Mc

When one examines the other FCC Rules and Regulations, it is evident that the aviation services should harbor and protect what assignments they now have. Furthermore, it is evident that either the 5000 Mc or 15,400 to 15,700 Mc assignment would suffice based on the other factors affecting the choice of radio frequency. Although advantages in size would result from the 25-kMc region, it is closely associated with radars in this band and is severely limited by rain and absorption, requiring some 15 to 20 times the power of the 15 kMc assignment for the same operational range.

In choosing a radio frequency for a tactical landing system, one must remember that its most important use will be in other parts of the world and not the United States. The ability to establish a landing facility quickly in an overseas tactical environment must be kept in mind. Frequency protection in the United States is under the jurisdiction of the FCC. The ITU (International Telecommunications Union) is the usual clearing house for international frequency problems. However, the FCC and ITU relationship is such that the same service is normally guaranteed overseas. This is probably particularly true of the microwave region that has not developed as extensively commercially abroad as have the lower frequencies. It is, however, a serious concern and more detailed studies should be conducted for assurance of the international use of the landing system frequency.

This would be one of the major objectives of the rapid establishment of a "Signals-in-Space" standard. Such a standard would then be clear notice of the military intent of using the band and the FCC would aid as would other governmental bodies (state). Without a standard, there is no assurance that the bands of 5 kMc or 15 to 16 kMc, which are most promising, could be retained indefinitely without usage. The ever-expanding demands for telecommunication services in this frequency area (airborne radar, ground radars, radio altimeters, microwave relays, satellites, space-navigation, and communications-TV, etc.) could well result in the loss of these bands.

The cost of attempting to open a new band, encouraging industry to equip and instrument for its operational application can readily run into tens of millions of dollars. This national resource, which resulted from World War II efforts and subsequent military developments, should not be lost to tactical landing for the lack of a system standard.

b. Frequency Stability and Channelization

The two bands that appear most favorable for a Tactical Landing System (5 and 15 kMc) have 250 and 300 Mc wide frequency allocations, respectively. The localizer assignment for ICAO is in the 108 to 112 Mc band and provides 40 channels by assigning facilities each 0.10 Mc (100 kc). The art of channelization and frequency stability at this (100-Mc) part of the spectrum is excellent with many ways of synthesizing literally hundreds of frequencies with a single unit. The 100-kc channel spacing allows for crystal drifts, modulation intelligence bandwidth, and variation in IF bandwidths. Since the VHF intelligence is but a few kilocycles, the crystal stability is the primary consideration. Some thought is being given to the 50-kc spacings in the upper end of the communications (VHF) band near 135 Mc.

This channelization is 1 part in 1000 when comparing the channel separation with the carrier frequency. Consequently, 1 part in 100 thousand (1 kc or 10^2 frequency stability is a typical practice--neatly keeping the signals inside the channel width with perhaps 100 to 130 db adjacent channel protection.

If this logic were carried to the 250-300 Mc width (frequency allocation) which is now available for a tactical landing system, 10^5 is equivalent to about 150 kc at 15 kMc. By going to a 10^6 frequency stability, this would provide about 15 kc of channelization accuracy. Assuming the channels were spaced 1 Mc apart, a total of 250 channels could be generated.

A table will make this clear.

<u>Spacing (Mc)</u>	<u>No. of channels at 5 or 15 kMc</u>
1	250
2	125
3	83
4	62
5	50
6	41
7	36
8	31
9	27
10	25

Even with a 10-Mc spacing and 10^5 accuracy, a 25-channel system could be developed. With the multiplexing techniques already demonstrated by several manufacturers, a single channel should serve all the functions of a tactical landing strip such as a glide path, localizer, DME, markers, etc., without allowing extra bandwidth for a "pairing" system as in the ICAO-IIS. It is urged, however, that, as the modulation and frequency stability criteria are established in the "Signals-in-Space" standard, some tight reins be maintained. There is a desire to have not only an Air Force "common" tactical landing system, but also a DOD or Tri-service common system (references 27 and 61). Ultimately, one must also face the FAA/ICAO (references 4, 61, and 24) standards for the global support that may come through the civil applications (installations at major bases around the world) that would appreciably aid the tactical and logistics problems.

Thus, it is suggested that perhaps only a part of the 250 to 300 Mc assignment be initially used (that part which the 1967 state-of-the-art permits) and that, by developing better frequency standards for air and ground (say 10^6 or 10^7), the remaining portion of the 250 and 300 Mc assignment can be more effectively used. Phasing of equipments making more efficient use of bandwidth, and thus providing growth potential, could be considered at some future date. At present, it would seem that a 10-Mc spacing and ten channels would suffice for a few years. This would leave about two-thirds of the band available for continued development, for joint service channelization, and civil matters.

The early TACAN 126 channels were reduced to about 80 to 90 because of interference from other services and this must also be considered here. Potentially, by using carefully shaped (spectrum controlled) modulation, beams, and good frequency stability, growth to a 100-channel system is possible.

Since many of the problems are similar to TACAN in siting, number of units, common military service, and civil use, the 100-channel potential seems a reasonable solution. This would suggest that channel spacings of 2.5 to 3.0 Mc be the future goal and that 10 Mc remain a current objective. More will be said on the effect of beam coding on this matter in the next section. It will be noted that pulses with a rapid rise time create requirements for wide channels (0.1-usec rise time is about 10 Mc). Pulse-multiplexing to use pulse rise times in hundredths or thousandths of microseconds (nanoseconds) is not advisable because relative amplitude measurements essential to most beam systems are difficult to achieve with closely spaced ground units.

c. State of the Art (Choice of Frequency)

Both the 5 and 15 kMc as well as several other microwave bands are fully engineered with many choices of transmitting tubes, crystal-controlled oscillators, channelization means, microwave components, and antennas. The industry can provide at least ten qualified suppliers of such items as tubes, microwave switches, receivers, local oscillators, antennas, etc., so that the Services would not be dependent on a single supplier of some proprietary units in either radio frequency region. Competitive system development organizations (about five to ten are experienced) and competent manufacturing organizations and suppliers (about 50 are qualified) exist for both 5 kMc and 15 kMc and make for a good competitive situation which should result in minimum development and production costs.

Furthermore, the modular concepts of the overall Tactical Landing System development can be shared by industry, since there will be several breakdowns of air and ground units--yet with each fitting the "Signals-in-Space" standard.

d. Modular Use of Ground Radiating Elements

When using the various elements of the Tactical Landing System, one should recognize that the height in wavelengths above the surface must be the same for all elements. DME vertical lobing that varies with glide path or localizer guidance can create serious problems (reference 19). The cases of pulse, multiplexing where several separated facilities operate on the same radio channel but are separated by pulse codes also create problems along similar lines. The desired signal may be interfered with by a ground reflection maximum (lobe) from an

interfering (reflection) source while the aircraft is in a null of the desired (direct) signal (up to 20 to 30 db in depth). Furthermore, the approach flight path may be such as to place the aircraft nearer the undesired signal for part of the flight (one passes near J.F.K. localizer beams sometimes on an approach to La Guardia). The bandwidths mentioned earlier in the discussion of frequency and channelization are determined by the frequency stability and the nature of the modulation. If sharp pulses requiring nanosecond leading edges are involved, the channels can have band-pass requirements (air and ground) of up to 100 Mc. This wide bandwidth makes the equipment more susceptible to jamming and interference from other sources (including self-interference). Airborne radars are notorious for interference because of their greater number, poor frequency control, high gain beams, and their elevated locations. Also, the airborne source of interference cannot be controlled with respect to location or "horizon" (line-of-sight) protection as in the case of ground units.

The modular use of the elements of the Tactical Landing System must bear all this in mind, since one does not have weeks to work out a tactical frequency channelization scheme to minimize interference. The tide of a battle in a theater can cause the tactical ground units to move into different spacings and beam relationships, perhaps each day. For this reason, the "clear" channel concepts appear the best. Sharing of one wide channel by several ground landing radiations is complex. One must remember that dozens of such units could be in operation in a tactical theater and the effect of the modular aspects of the equipments on the frequency channelization to avoid interference is important.

e. Choice of Frequency Affected by Modulation

In the selection of modulation techniques, it is possible that at first a fully compatible modulation standard for scanning and static beam antenna systems cannot be found. It is quite possible that this situation will not prevail. However, even if it does, the major aspects of a common Tactical Landing System in the Air Force will have been met with the selection of the basic radio frequency. The major benefits will have been derived by this one design. Standardization of the elements of the basic transmission system (ground transmitters, power, siting, air receivers, local oscillators, channelization, aircraft antennas, etc.) will have been achieved.

With modern microelectronics, the addition of a somewhat different decoding in the aircraft would not be a major disadvantage. The frequency channelization could be worked out for the two modulation methods (for example, the lower end for scanning beam modulation and the upper for static beam modulation). In due time (if not available initially), a creative effort (as described under the monochrome-color TV analogy) can be encouraged. Thus, perhaps a 95 percent commonality would exist between the scanning and static beam selection.

The choice of frequency is the most important step toward a multi-function Tactical Landing System, as it immediately establishes the antenna sizes, the channelization methods, and would provide a firm guidance for industry. As a result of such guidance, more creative effort will be funnelled into the main stream, minimizing the proliferation and cost of the diverse landing system developments.

5. STEP IV--BEAM AND MODULATION CHARACTERISTICS

Although this discussion would apply to most frequencies, it should be noted that it assumes that a microwave frequency with good stability is the likely resolution of Step III. In addition to reviewing means of "earmarking" (coding or modulating the beam) so that the airborne signal processing circuits can determine fly-up and fly-down (and the actual angle either side of the indicated flight path), the beam (or beams) must be lobe-switched, scanned, mutated, or otherwise shifted in angular position by one means or another. This change in beam position (as in ICAO-ILS) must be identified with a change in modulation. If only the 90 to 150 cps signal of the ICAO-ILS or the 30-cps of the VOR were suitable, the bandwidth needed for the beam intelligence would be less than that required for frequency stability (even 10⁷).

However, such modulation would be an excessive and unnecessary restriction on the development of a Tactical Landing System that has the objective of meeting the varied landing requirements of the Air Force. For example, a modular airborne DME function using pulses to obtain accuracy commensurate with landing may require a bandwidth of a few megacycles. This restriction should not be applied to a tactical system even though the FAA is now considering such a scheme in a microwave radiating system heterodyned to the 100 and 330 Mc regions. Of all beam guidance techniques developed to date, the scanning beam has proven to be the most versatile. Some ten years of development and

millions of research and development dollars support this technology (references 5, 6, 15, 24, 29, 31, and 83). It can be used with 8-foot, 6-foot, 4-foot, or 2-foot antennas. The limits of the lowest useful angle are directly related in an inverse manner. One of the problems scanning beams encounter is the limited "dwelling" time of the beam on the aircraft antenna. Since the beam is in continuous motion, it is directed at a specific angle only for a few milliseconds. As it moves past a receiving antenna, the signal level rises and falls according to the beam shape, and this is utilized in the receiver for angular measurement by a beam-splitting technique. Since the beam's angular velocity must be high to provide fresh guidance signals, updated at least every fraction of a second, the encoding requires a rather high duty cycle, at least for the instant it is being received.

The modulation must establish the "pointing angle" of the beam in milliseconds. This requires some form of high-speed and high-resolution beam encoding to establish this reliably and precisely. The use of pulses and magnetrons has been encouraged by the current state of the art. The pulses have the advantage that they can be treated with modern digital techniques in the aircraft using micro-miniaturization elements developed initially for the computer industry.

Of equal importance is the fact that, though other techniques exist, pulses are the most practical form of obtaining a DME function of reasonable accuracy--less than 100 feet (references 18, 19, and 31). A rise time of 1 microsecond has an associated bandwidth of about 1 Mc, and a rise time of 1/5 microsecond has an associated bandwidth of about 5 Mc. A minimum rise time similar to the latter is needed for the accuracy of a landing DME (reference 31).

Thus, there would appear to be a need for a modulation that uses a rapidly rising pulse for both DME and to provide beam encoding. Furthermore, the rapid rising time of a pulse results in the ability to utilize more pulses per unit time so that considerable growth potential is provided for future cases of wide azimuthal guidance (equivalent to a sector of an omnirange), ground-to-air data transmission of the beam, interrogation of the AIMS, security IFF beacon, etc.

Two basic encoding systems have evolved. One, utilized in REGAL by Gilfillan, has a multipulse, digital message repeated (with changes) each few hundredths of a degree of scan (reference 121). AIL utilizes a variable pulse spacing related to vertical

or horizontal angle. Both schemes also use spacing needed for the multiplexing of a precision (50-foot) DME. The same code structure of the FAA-AILS serves for DME, vertical and azimuthal guidance so that a single, time-shared, airborne processor handles all three transmissions, saving considerable equipment and complexity.

For comparison purposes, the FAA system uses an airborne 330-Mc receiver with separate beam modulation for the glide path, a 110-Mc receiver that also has separate beam demodulation, and a 1000-Mc transmitter-receiver with high duty cycle pulses for DME (limited in accuracy for landing because of the 1-Mc channel spacing that forces a slow rise time—reference 19). This proliferation of air equipments with its complexity and inefficient use of the spectrum should be avoided in any new landing systems with today's technology. Most of the ILS developments were the results of 1940-1950 technology, before modern digital techniques, microwaves, etc.

Some additional thinking on these lines (of modulation) to fit the various modular ground and air units need further encouragement.

The beam coding should satisfy the following:

1. Fixed beams
2. Scanning beams (narrow)
3. Scanning beams (wide)
4. DME, multiplexed using the same transmission standards as angle, but possibly one wide channel for airborne transmission.
5. Combination of fixed and scanning beams
6. Compatible localizer
7. Glide slope and flare guidance signals
8. Transmission of future data such as RVR, clearance line, equipment checkout signals, wide azimuthal signals, markers, etc.

The integration of a GCA function with the scanning beams used for guidance at some future date should not be overlooked. Both Gilfillan and AIL demonstrated the interchangeability of about 80 percent of the ground units between beam

landing guidance and GCA. Both techniques could be multiplexed on the same ground units, thereby providing a savings in equipment. Procurement costs, logistics, and airlift problems would all benefit from such a combination. Pulse rise times of about 0.10 microsecond are needed to provide sharp targets for the GCA displays and should be considered in any channelization scheme.

Also, even at low power, normally utilized for one-way transmission, the ground units can provide a limited short-range radar capability for target range measurement near touchdown. This DME function (really radar ranging) offers the intriguing possibility of a simplified means for passively (airborne) establishing only near touchdown the exact distance to go. Some experience with helicopters indicates that the target return (on a range-gating only basis) is good for about 1/2 to 1 mile. (Note that some Army man-pack radars are capable of "seeing" trucks and similar sized objects at a few miles.)

This potential suggests the retention of a narrow pulse for precise range gating of this (modular if needed) addition to the scanning beam or fixed-beam version of the Tactical Landing System. The narrow pulses and a high prf aid in overcoming the ground clutter, and simple range gate filters (such as IFF decoders) with tapped delays out to about 20 microseconds allow several samples to be taken and integrated. A long pulse with a low prf does not suffice.

As noted previously, one can argue for more of an apparently good thing and suggest a nanosecond pulse coding (reference 95). However, this does not appear necessary, since large bandwidths are needed, making the equipment more susceptible to enemy jamming and interference. Vertical, glide slope, ground reflection, and lobing cannot be eliminated this way. Furthermore, signal separation by pulse multiplexing is complicated. In cases such as SSR (IFF) where the ground initiates and processes, "defruiting" is very helpful. Also, SSR is only a ranging system (no coding is radiated for angle), with airborne reception of several ground stations, each with widely different signal levels and the need to compare amplitude as well as range. SSR experience would suggest a very detailed pulse density and signal level study is first essential if a pulse-multiplexed system is considered.

More details on the interaction of frequency, beam-widths, beam lobing or scanning, and modulation on course quality and the utility of a Tactical Landing System appears in a section devoted to this and possible modular designs. Suffice it to say

that it is likely that a good research and development effort can produce a "Signals-in-Space" standard that will permit both a scanning beam and a lobe-switched beam (fixed antenna) to be compatible with the same airborne receiver. If such is the case, then the equipment applications will depend on the landing requirement of the environment, mission, and aircraft flight characteristics. Beamwidths with some variation can be tolerated and processed in an airborne, common receiver, with skillful system planning and a well thought out and proven beam-coding technique.

Some ground units may appear different physically--fixed vs scanning beam, size of antenna (DME or no DME), etc., but the modulation means for establishing the guidance path in space can and should be common and thoroughly standardized. This standard must have the needed flexibility to meet the operationally significant variations of (the modular) system design. Combined lobe-switching and scanning beam techniques in the same ground units are also possible, bringing often the best of both to meet certain criteria (lobe-switched for clearance and scanning or path control).

6. STEP V--"SIGNALS-IN-SPACE" STANDARD

Step V is, of course, the most significant step in the process of developing the Tactical Landing System. With the knowledge gained from Steps I through IV, it is possible to judge for the first time whether a proposed standard is applicable. Since there has been no centralized source of the knowledge required for the interrelationship of diverse technical fields, a "Signals-in-Space" standard could not be written for a Tactical Landing System. The state of the art fortunately now appears to be ripe for such an accomplishment. This step will determine the radio frequency to be used, the number of channels, the stability of the ground transmissions, the stability of the airborne receiver, and the nature of the beam encoding for lobe switching, scanning, or other beam guidance means.

It should be noted here, however, that we have not gone afield into "time-difference" guidance techniques as they do not seem to fit the tactical landing picture. A suitable time difference localizer, for example (two radiators on each side of the runway), has not been reported as being successful, though considerable effort in France (CSF) and England (Elliotts) has been expended. Wide ground beams are necessary to simultaneously receive both signals in the aircraft. Wide beams are plagued with reflections and course perturbation. The radiation of an angular beam of one form or another from a single site or a combination of vertical and horizontal sites is considered.

furthermore, the desirability of having all landing guidance signals received by the same airborne receiver is obvious. Successful, known techniques lead more logically to a beam type system.

a. DME

Many of the techniques tested to date have a means of providing in one form or another an airborne DME function (references 31, 56, and 95). The added DME function, even if it uses fully compatible equipments (frequency, antenna, etc.) must be given some thought with regard to the modulation methods and the means of multiplexing on the beam signals. The REGAL system used one means of DME multiplexing, the AILS-FAA system another, and a third is offered by the new STATE system of Honeywell. TACAN multiplexed DME with angle in a pulse-sharing method (pulse multiplex), and other systems do it with different pulse length, widths, or spacings. Frequency multiplexing has also been used, but if it can be avoided and provided on the same radio carrier of ground equipment that establishes the vertical and horizontal guidance so much the better. The beam modulation can be a simple matter when time-sharing the signal between two beams. DME, if it is the third multiplexed signal, should be optional for reasons to be given, but, when used, it should be a full partner in the multiplexing function. If not used, the multiplexing function is open (open time slots or code positions, etc.).

Whether the DME should be all-around looking so that it could be used for orbital flights to intersect the localizer at the appropriate distance (suitable for bracketing and stabilization before descent) or for only a sector, is important before equipment and techniques are evolved. An area navigation system that may be available (DQ, OMEGA, LORAN, DECCA) is justification for a sector DME coverage rather than a 360 degree coverage. This should be resolved in the signal standard. Since a precision DME is really needed for landing (say 50 feet for computing flare, air drop control, and off-set aiming) or establishing height limits (R-O) and is economically achievable in the microwave region with sharp pulses, the bandwidth involved must be a guiding factor in the channelization scheme.

The thought that the urgency of a tactical system might call for, say, a 10-channel system to be developed at high priority in only a fraction of the total 250 to 300 Mc allocated band must be kept in view, since a more fully developed means of channelization could evolve in due time without jeopardizing the Signals-in-Space arguments. The TACAN clear channel vs the ANDB pulse multiplex channels for DME are examples of everything being nearly common (frequency, function, purpose), but

only a slight bit of incompatibility resulted in a major defeat for the ANDB-DME that had already been proposed by the U.S. to ICAO for international adoption and had been funded for 450 installations, most of which were already in. The stalemate that developed cost perhaps hundreds of millions and delayed a useful DME to both Civil and Military for nearly a decade after the time it could have been available. This is only one example of the significance of this step. The failure occurred mostly because a good effort had not been put into Steps I through IV of our synthesis of a system concept. The political, economic, and international factors became predominant since little good data was available to the so called "VORTAC" committee. The committee required over a year of independent research and dozens of meetings to get at the technical facts that should have been available before the signal standard conflict developed.

Another good national example is that of compatible color televisions. Although the battle is over and the standards have been established that permitted the expenditures of the vast resources needed to make a production unit available to the public, the record is probably more fully documented than that of TACAN by the good graces of the IRE. This august body of scientists and engineers was drawn into the battle among three incompatible but proven systems. The criteria of color working compatibly with the already established standards and operation of monochrome TV were overwhelming. After a struggle of many years, the original FCC decision (frame-sequential) was abandoned for "dot-sequential," but a fully compatible scheme.

To avoid going into the details at this juncture (which incidentally are not only informative, but germane to the problem at hand, since not three but perhaps a dozen Tactical Landing Systems exist), we will note that other sections cover parallel examples of establishing equivalent standards to those of a Tactical Landing System. The parallelism is somewhat surprising. Research on the scientific methods used before presenting their technical solution of the incompatible color TV impasse to the special U. S. Senate committee for approval (indirect since the FCC was the responsible body, but had approved another system) is worthy of deep study by those individuals who must face this problem in the tactical landing area. Success or failure is apt to involve tens of millions of dollars so that it cannot be taken lightly. Possibly, after data from Steps I through IV can be placed before such a body, the most experienced and mature individuals of the electronic, government and aviation communities should establish the standards.

Before the "Signals-in-Space" standards can be written and agreed upon (even within the Air Force) the various concepts

should have at least been examined by means of experimental models and flight tests. A preliminary signals-standard might first be outlined for guiding these developments. This might have to be recognized as a somewhat risky business and extreme control exerted to avoid a premature unsatisfactory standard. Yet, a standard must be based on something other than opinion and technical estimates. The hard facts of landing guidance would suggest that three or four experimental tests be conducted with the various Air Force users and with some coordination with the other services and DDR & E. As noted in Step II, only sample systems, limited to those that seem to fit (with commonality) the operational needs, should be tested. These flight tests should be thorough and quantitative, using the actual types of aircraft, and in environments that are typical of the tactical situations (reflections, clearances, and hasty installations that are moved frequently).

Although, out of the three or four tested, perhaps not one (as it is then configured) will survive the Step V "Signals-in-Space" standardization. The quantitative, measured outputs will determine the nature of the standard. As in the examples cited, the development of a working, proven model is needed before a meaningful standard can be written to describe the units and system features. The standard may improve on the test model techniques, but its validity can only be established by scientific, measured means--not simply another committee.

The standardization committee's function is important at the right time when it has material upon which to deliberate and decide. The decisions can be complex, involving interagency economic, and (hopefully) mostly technical matters. Steps I through IV provide this body of knowledge that the standards committee will finally use in preparing the "signals-in-Space" standard. ICAO standards, IEEE standards, FCC standards, etc., should all be studied for guidance in such a complex field.

The first tentative or provisional standard with limited commitments and a well-established review period for revision is a good administrative means of allowing some ingenuity and flexibility, and yet leaving room to correct any blunders. ICAO has been somewhat successful with this method of standardization. It allows progress (under controls), and attempts to avoid an "over-commitment" that would economically restrict or dictate the standard. When this occurs, it is usually with considerable sacrifice and loss of time.

b. Interagency Standards

The Air Force does not stand alone in the problem area of tactical landing (references 27, 61, 62, 98, and 103). Consequently, the preparation of the standard for the Air Force should bear in mind some tri-Service problems and attempts should be made to avoid them. If each of the Services comes forth with different standards (for example, frequency incompatibility), a stalemate is likely to continue for another decade with further proliferation of systems. However, there is evidence that a joint common standards committee of the Services and DDR & E would find more mutual benefit and interest than are first apparent. There appears to be a real desire finally to get something accomplished in this tactical landing area.

Furthermore, in the case of the Air Force standards for a Tactical Landing System, the missions and types of aircraft are so broad as to encompass nearly all variations. Thus, a tri-Service standard would probably reflect Air Force needs more fully than others. The aircraft carrier landing problem is distinct, but considerable progress has been made through the Navy's established ACLS (All Weather Carrier Landing Systems) office. At least a focal point exists in the Navy which is difficult to discern at present in either the Air Force or Army. Each Service will be doing its "homework," but with the guidance of the "Signals-in-Space" concept. Overlapping areas of tactical significance are treated with common signals and ground equipments.

Even a common (tri-Service) decision on the choice-of-radio-frequency would be a welcomed achievement of the "preliminary" standards effort. If more details cannot be established, this would allow (with some restrictions on the beam and modulation methods) a coordinated, experimental program to be initiated.

The second "Signals-in-Space" standardization step would be the detailing of the modulation and airborne demodulation techniques (descending) to allow for the maximum of flexibility. If it cannot be fully achieved, which is also a possibility, the extent of the diversity can be controlled. What cannot be made "common" and, therefore, justifies a special modulation or beam-forming scheme, can be limited. What is likely to be suitable to the vast majority can proceed with full implementation in its various forms while retaining the "Signals-in-Space" standards.

7. STEP VI--MODULAR DESIGN

Once the decision on the "Signals-in-Space" standard is confirmed, the way is clear for several parallel developments

to this standard. Some are "building block" modules from basic capabilities to combinations for more demanding requirements. Others may be a completely integrated ground system. Table IV and Figure 44 describe such a modular concept. This will be a matter for careful study so that not too many variations develop with problems of inventory. The major variations are in the ground units: the air units perhaps being nearly all common, but with a possible simplification (for example, DME or no DME) and variations in path width and angular coverage.

a. Module No. 1

This module utilizes beams about 2.0 to 2.5 degrees in width and is chosen since this is suitable for the normal approach glide angle for jet aircraft such as the Century Series fighters and jet transports. It creates a path equivalent to the standard ILS path with a small fixed (lobe-switching) antenna. The size for Ku- and C-band (15 kMc and 5 kMc) is 2 feet and 6 feet respectively. Because the beams are fixed, the course width is preordained to a great extent assure the possible (and expected) locations of false courses due to the side lobes. If necessary, these are operationally eliminated with side-lobe suppression or "clearance" arrays (such as the FAA waveguide localizer). However, considerable, additional complexity is involved. The vertical path should not be elevated more than about four degrees for this reason. In tactical sites for steep approaches (with COIN, STOL, helicopters, etc.) at 6 to 10 degrees, this should be avoided. This configuration would supply a low ceiling capability of about 200 feet and a 1/2 mile and permit establishment of appropriate GPIF (approach-aim) points.

TABLE IV
EIGHT POSSIBLE GROUND UNIT MODULES EACH
COMPLYING WITH COMMON "SIGNALS-IN-SPACE" STANDARD

Module No.	Beamwidth (3-db points)	Beam Comparison Technique	Linear Course Width	Path Characteristics	Approximate Size (Ft.) <u>Ku</u> <u>C</u>	Comments
1.	2.0°vertical	Lobing(static)	$\pm 0.70^\circ$	Single path between $2.5-3.5^\circ$	2 6	False course side lobes may be present
2.	6.0°vertical	Lobing(static)	$\pm 2.5^\circ$	Single path between $6.0-8.0^\circ$	1 3	" " "
3.	8.0°horizontal	Lobing(static)	$\pm 4.0^\circ$	Single localizer	1 2	Limited width needs side lobe suppression
4.	2.5°vertical	Vertical scanning beam 2.0 to 30°	Selectable from ± 0.70 to $\pm 10.0^\circ$	Selectable from 2.5 to about 15°	2 6	Sensitivity determined by vertical angle
5.	4.0°horizontal	Horizontal scanning beam $\pm 35^\circ$	Selectable from $\pm 4^\circ$ to $\pm 20^\circ$	Localizer centerline	1 3	70 degrees horizontal window
6.	0.50°vertical	Scanning beam 0 to 10°	Selectable from ± 0.3 to ± 3.0 depending on angle	Selectable from 0.5° flare to 8° steep approach	8 24	Flare for low visibility fighter and transport
7.	Same as 4 vertical	Same as 4	Limited to $\pm 0.70^\circ$ to 1.4°	Side lobe elimination. Single path 2.5° to 10°	2 6	SPN-41 glide path
8.	Same as 5 horizontal	Same as 5	Limited selectable from $\pm 3^\circ$ to $\pm 6^\circ$	Localizer centerline	1 3	Single path but no clearance needed

P - PROPORTIONAL DATA

F - FALSE COURSE

C - CLEARANCE (NO FALSE COURSE)

→ SCAN ANGLE (LIMITS OF RADIATION)

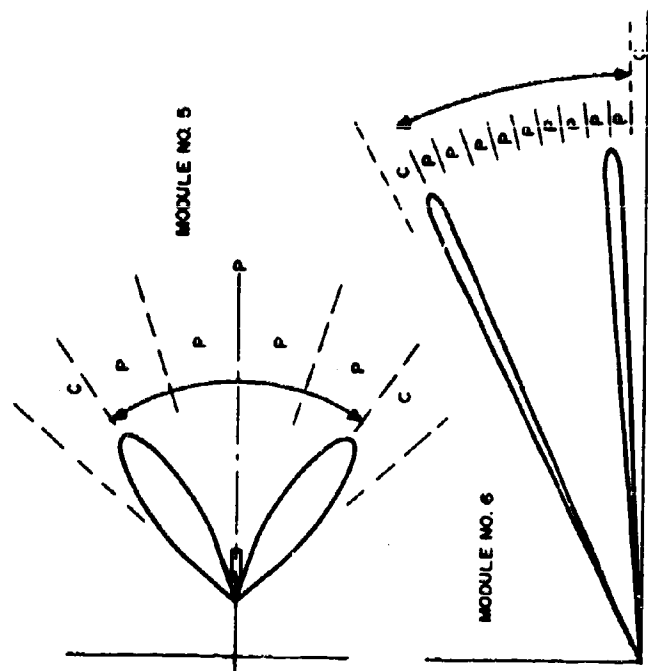
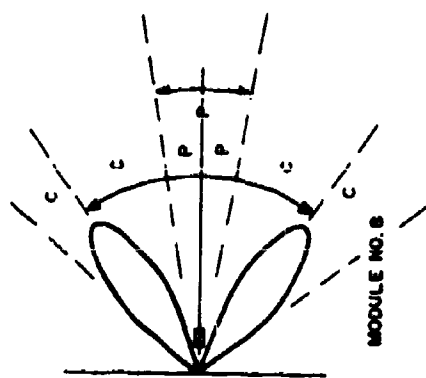
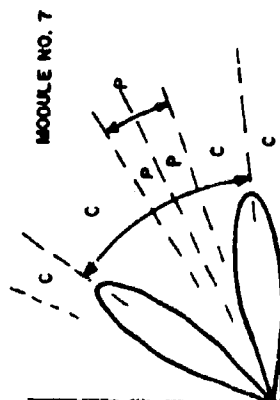
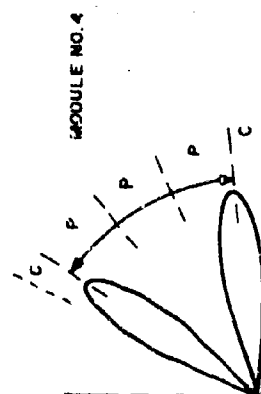
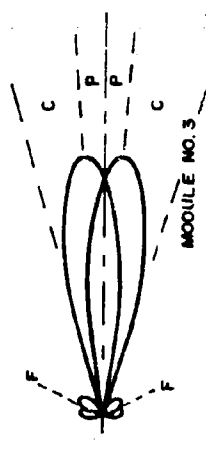
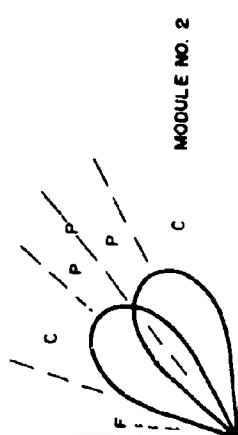
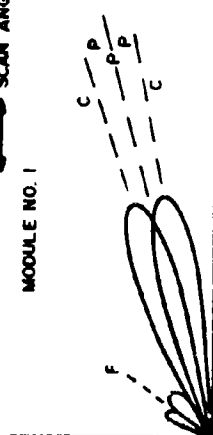


FIGURE 44. SAMPLE OF MODULAR CONCEPT

b. Module No. 2

This unit overcomes the high angle limitations of module one and should not be used for low angle approaches. With beams about 6 degrees in width, the lowest (clean) path angle is about 6 degrees (even then a half-power signal is radiated at zero degrees, creating some meter nonlinearity by illuminating the ground). Module 2 will not have false courses below a path at around 7 to 9 degrees and will have wider cross-overs (course widths) commensurate with the wider beams. This is acceptable as noted previously since steeper angles call for wider courses. The change in beam signal per unit angle known as a db/degree criteria is best met with a cross-over at about an $\frac{1}{2}$ -power point. This can be varied at higher angles slightly by minimizing ground reflections as they affect the meter linearity when high level beam overlap is used. Module 2 might serve as a STOL Glide Path.

c. Module No. 3

The horizontal course widths are usually wider since the aircraft maneuvers relatively more in the horizontal plane with respect to the landing site than in the vertical plane. The usually (ICAO) accepted course widths are from ± 2 degrees to ± 4 degrees or sector widths of 4 and 8 degrees respectively. The suggested 8-degree beamwidths are adjustable for about these course widths. The beams are symmetrical on either side of the centerline of the landing or drop area and thus illuminate the minimum number of objects (on either side). Some form of side-lobe suppression is necessary to avoid false courses. If one were to widen the beams to avoid nearby false courses then the db/degree change between the beams (skirt slopes) would not be adequate for the course stability (reflection and low db/degree add together).

Many years of experience and some four to five systems have proven these figures to be near optimum.

Although the wider localizer beams are at first inviting (since they could be made wide enough to avoid side lobes and false course out to say 35 degrees from the course), the slope of the beam at cross-over (on course) creates such a small db/degree change. Any minor perturbations to the beam from fixed reflecting objects, moving objects, vertical lobing (nulls in the vertical pattern of the horizontal guidance) result in course bends, reversals, shifts and nonlinearity. The difference

in path length can be long or short. In some cases "leading-edge-tracking" will provide some improvements. However, the many problems of extreme bandwidth, previously noted, must then be resolved. The most bothersome reflections are often from the ground in front of a glide path. If, for example, a wide vertical beam (say 6 degrees) is forced on the ground for a 2.5 degree path, deep vertical lobing with many adverse effects on the pilot's display (flat spots, reversals, etc.) appear. To overcome this by leading edge tracking, a cycle of the carrier frequency (two Fresnel zones) must be considered (references 45, 46, 47, 48, and 109). This would require bandwidths far exceeding the available frequency allocations.

d. Module No. 4

This module uses a scanning beam (mechanical or electrical) and has the advantages of flexibility in the selection of path angle over a wide range without concern for side-lobe suppression. Course width is also flexible. It has a problem of mechanically or otherwise scanning a beam of some sort. The inherent advantage of simple side-lobe suppression provided by scanning beams can be of considerable significance in a tactical landing system. The "Signals-in-Space" standard should accommodate continuous scanning beam techniques since they seem reasonable answers to not only narrow beams for low angle flare, but also wider beams for standard and high angle glide paths. Side-lobe suppression is avoided in both cases. Both narrow and wide beams are essential to USAF for tactical operations. The steep angle of the helicopter and STOL often permits 1/10 obstacles lines and thus a wide selection of potential landing points in a tactical area.

Module 4 will be physically small for light helicopter, trucks, or even man-pack means of installation. Fortunately, as the steepness of the glide-path angle increases, smaller antennas with wider beams can be used. The wider beams do not permit paths to be selected much below about 1 to 1.5 times the width of the scanning beam. Signal radiation is terminated when the scanning beam starts to point near the ground. However, a 2.5-degree beam could readily produce V/STOL, STOL, and helicopter paths between 4 and 20 degrees. The over-swing of the beam beyond the described approach path provides clearance signals and allows for wide course widths at high angles.

A brief analysis of a steep helicopter approach (15 degrees) suggests that a course width of about +7 degrees, -5 degrees, or a total of 12 degrees be allowed. This would place the upper full-scale indication at an angle of 22 degrees. If the beam continued to radiate as it scanned to 30 degrees, an

8-degree sector of protection (above the course), and suppressing of side lobes would prevail. At such steep angles the approach speed is reduced (often around 30 to 45 knots) and wind shear can be quite detrimental to following a narrow course. If a wide course is not provided, the "tightness" of the pilot's deviation indication is in excess of his control limits. In other words, the narrow course at high angles results in an overly active deviation indication with a poor coupling between the course width indication, pilot, and the aerodynamics of the situation (references 104 and 122).

This is illustrated in Figure 41 by the fact that a glide path at 3.0 degrees with a width of 11.0 degree is readily flyable since its longitudinal course width is about 1400 feet at a height of 100 feet (CAT II). If this same course width in degrees is used for a glide path at 15 degrees, the width is only 52 feet or a change of sensitivity of over 25 times. Furthermore, at the steeper angles, the forward speed is reduced so that wind gusts, shear, and directional changes can be far more bothersome than at the flatter angles where higher speeds are permissible. To keep the sink rate within reason, any steep angle approach is slower (in forward speed) and thus winds have much larger effects. A 15-knot wind shear on a 45-knot approach is a change of 33 percent of ground speed. The glide path indication, being a ground reference, is thus adversely affected. These two difficulties of steep angle approaches are additive and create serious piloting and display problems.

It would appear that a module such as Module 4 with flexible selection of both path angles and sensitivities over a wide range would be essential for coping with the varied tactical environments these aircraft encounter. If flat angles with clear approaches are available, other aircraft will suffice, but the basic justification for the STOL, and helicopter, is the small landing areas, and adverse obstacle lines. This permits the Field Commander a wide range of operational decisions for air operations not possible with fixed-wing jet-powered aircraft. Thus module 4 is an essential element of our Tactical Landing System.

e. Module No. 5

This is another of the examples of modular system concepts and is likely to be modified in detail with further study. It serves, however, to illustrate a point in the concept. This unit provides an azimuthal guidance signal by means of 4-degree beams scanning over about 35 to 50 degrees either side of the centerline.

The beams are by past experience (references 6, 57, and 99) narrow enough for a clean localizer signal, since scanning beams can "gate" out reflections from objects removed by a beam-width or so of the centerline. Furthermore, it permits antenna in sizes of 1 to 3 feet to be designed that can be readily used for man-pack units. The 1-foot unit at Ku-band would be such that the antenna structure could be an integral part of the package and no assembly at the site would be necessary, merely leveling and bore-sighting for the correct clearance lines. Simple, resonant torsional drives with infinite life (requiring low power) can provide the wide angle scanning without expensive phased arrays of a "Wullenweber" type antenna. The antenna in a circular housing would be fully protected and not affected by wind, much as the rotating rotodomes on Navy aircraft. The usual course widths for localizer flying ± 2.5 degrees can be readily achieved. Reports that helicopter IFR flight needs wider localizer courses (about 20-degree sector widths--references 101 and 102) can be satisfied with a simple airborne adjustment of module 5. The same ground units could serve both the narrow fixed-wing course widths requirements as well as the V/STOL widths without ground unit modifications or adjustments.

This module is one of considerable interest in air-drop operations. It could be set up and operated from battery power almost anywhere. A DME modular unit could be added, sharing the same ground transmitter equipment by adding a ground receiver. Air drop accuracy could be considerably enhanced with horizontal alignment and precise range, from or near the drop point. Precise altimeters should also be used with the two functions.

The significance of Module 5 is that even with low ground transmitter power, modern airborne receiver technology permits signals to be received readily at distances of 10 to 30 miles. With a wide azimuthal scan, a large volume of airspace is covered. For example, ± 45 degrees by 10 miles is equivalent to a total area coverage of about 75 square miles. It is expected that Loran, Omega, inertial, and other self-contained navigation means within the aircraft could find this cooperative signal on the ground. Once the coverage is penetrated, terminal accuracies are then available far exceeding these self-contained systems. The scanning beam can provide R- θ coordinate data (with DME) throughout its coverage (much like a minute VOR-DME or TACAN). It is, however, much more precise and has landing localizer course qualities and accuracies exceeding most self-contained systems by two or three orders of magnitude.

This unit can be used alone or with a vertical unit to provide a full approach capability. The sharing of much of the

power and electronics can be achieved with modular planning. However, packaging, so that separated vertical and horizontal sites or co-located sites can be employed is best. Discussions on siting will indicate the reasons in more detail, but one basic limitation of a co-located only (not separable) concept is that the flight path of the aircraft is directly toward the guidance units, and they can be blown over, damaged, or shadowed by the aircraft. Split siting overcomes this, optimizes the use of the available landing area, properly establishes GPIIP, and thus is likely to satisfy lower ceiling operations and higher safety criteria. It is not denied, however, that placing the two together in the same unit is useful in certain applications and the modular design includes this choice, but is not restricted to it.

f. Module No. 6

This module is a narrow, vertically scanned beam. Its main function is the guidance of a high-performance tactical aircraft throughout approach, flare, flare path, and to touchdown, utilizing minimum amounts of runway. Module 6 is particularly applicable to the Century Series fighters and airlift aircraft such as the C-141 and C-5A, but will serve many other types as well. When used with the precision DME function it will permit any GPIIP to be computed within the aircraft. Thus, each aircraft can have a preferred GPIIP, flare path, and touchdown, utilizing its own path computation, self-contained in the aircraft. The approach of many of these aircraft is so closely related to a successful flare and landing that the full landing guidance criteria must be considered. This is true even though a CAT III (b or c) capability is not an initial goal.

Flexibility of approach angle, GPIIP (approach aim point-- references 34, 35, and 36), visual contact height indications, and other features of a fully engineered high-performance landing guidance signal are obtainable in this modular design. It would be similar to the techniques that have been in test and development for some ten years so that engineering details should be available (references 5, 6, 29, 31, 56, and 57). This unit should be packaged into a van within the airlift packaging dimensions so that it can be airlifted in its entirety and installed in an hour or so without the assembly of any elements at the site. The airlift aircraft (probably a C-130, or equivalent) would serve as the flight inspection aircraft after delivery, so that an approved facility with monitoring exists, much as in a permanent facility; but all this to be done within two to three hours.

The IFR ability to cope with the long, flat, landing trajectory of the Century Series fighters (such as the F-101) would provide in most sites an additional 2000 feet of runway now denied because of the inadequate location of the GPIF. The beamwidth must be narrow enough to generate a path at a low point some distance from the radiator and to provide means of positive obstacle clearance. The typical threshold height of 8 to 10 feet and threshold path angles of about 0.6 to 0.8 degrees will be quite demanding of this modular unit.

Possibly, guidance to a location that is only over the threshold approach will suffice, but the examination of sample trajectories in a separate section of this report is invited. The radio altimeter, often considered by the Civil authorities and the airlines, is not considered suitable in this application because of terrain irregularities before threshold. After the new GPIF is established, this is even more evident. Certainly precise height from at least 150 feet is needed. The radio altimeter would require a level surface from 5000 feet beyond threshold to the touchdown point. The coordinates provided by Module 6 (including DME) permit flexibility of path, but a positive indication of the threshold conditions and the touchdown point. This type of guidance is important to the jet fighter if duck-under maneuvers, overshooting, barrier engagement, or loss of landing (deceleration) chutes are realistically considered. The acquisition of about 2000 feet of additional runway (under CAT I, II, or even III--reference 36), elimination of the high risk, and reduction of the number of accidents already attributed to duck-under maneuvering (reference 34) will readily justify this development of Module 6.

g. Module No. 7

This module is an attempt at simplifying the scanning beams for cases where only a single vertical angle, settable by the ground personnel, is desired. This is a typical requirement of the Navy carrier type landings (or SAATS) in which the limited cable area demands that a fixed non-flaring path be used that is about 3 to 4 degrees in elevation relative to the touchdown point. This could be achieved with something like Module 1, but the side-lobe considerations above and below the path are important. Often jet (steep angle) penetration from above the glide path requires deviation indicator protection up to perhaps 10 to 15 degrees to avoid the indication of a false course created by side lobes. Also, below the path it is essential that protection be given for full clearance down to the horizon, certainly without any false courses and with a positive, full fly-up indication.

This module uses a scanning beam, but utilizes only a small part of the scan angle for creating a path. The beam continues to scan and radiate beyond the small course sector, creating its own side-lobe suppression signal. A second (higher path) could be generated for STOL, but each sector is a discrete path determined by the ground personnel and the flight environmental factors. Both air and ground electronics are simplified for this unit over a fully encoded scanning beam, as is the case in Module 6. The coding for Module 7 could be designed to be compatible with that of Module 6 at the selected angles, so that the same airborne equipments could be used with either ground facility (similar to SPN-41).

Mechanically, another possibility exists for the design of Module 7 wherein a beam is scanned only a small angle (3 to 5 beamwidths) and the signal is then switched to a clearance signal on either side of the scanned sector. Thus, it is a marriage of scanning beams and static beams in this sense. The lower gain of the static clearance beams would require greater power to assure adequate signal coverage. The side lobes are often only 12 to 18 db down from the beam maximum, and the loss of gain of the clearance antenna must take this into consideration. Furthermore, side lobes should be at least 6 to 8 db below the suppression signal at all angles of concern. If the antenna is scanned over a wider angle to achieve this same result, the loss in antenna gain (clearance) is avoided and ground lobing due to wider clearance beams (in the vertical) are avoided. This is a choice that probably cannot be made except by hardware experimentation and with flight testing. However, the wide choice of technical options speaks well of this modular design (reference 7).

h. Module No. 8

Module 8 incorporates the same concept as Module 7 in the horizontal plane. Most of the same arguments prevail (loss of clearance antenna gain when limited scan angles are used, susceptibility to lobing, etc.). If, however, a high-power unit is used for radar (GCA) on the same frequency, it can be time-shared and used for the clearance signal such as in the FAA-AILS design (reference 6).

Another option of Module 8 would be a narrow scanning beam for long runways ($\frac{1}{2}$ -degree beam horizontally scanned) with a second (and wider angle) scanning beam taking over beyond about 4 degrees on either side of the course. This offers the side-lobe suppression with lower power, and this unit could be combined with Module 5, covering out to ± 30 to 45 degrees, but deactivated in the center sector (8 degrees) of the scan in favor of the

radiation of the narrower beams. Signal levels would probably assure adequate side-lobe suppression and perhaps even the same modulator-transmitters, etc., could be retained in a two-step method of "fine" and "coarse," much as is the case with two speed omniranges (references 72, 73, and 74). Thus, Module 8 might in reality be just another configuration of Module 5 and a horizontal-mounted Module 6. Or, it could be a combination of a static model similar to Module 3 with Modules 6 or 5 with the beams oriented to establish the best clearance and side-lobe suppression cases. Testing of such combinations is an example of the exploitation of the modular building block concept.

1. DME Modules

The additive ground units for DME functions are essentially a receiver, antenna, and encoding means for multiplexing the existing ground transmitter. This unit is an element of Modules 1 through 8 and is already available for angular guidance. There seems to be no need for a separate DME ground transmitter if skillful system planning is used.

The means of establishing the return path to the aircraft is important. In REGAL, the aircraft equipment interrogates the ground units only after the airborne scanning beam receiver recognizes the presence of the beam (through its digital angular decoding circuits). Then it uses the high gain path of the narrow beam ground antenna to establish a path to and from the ground for the period of beam dwelling on the aircraft. The DME relays were multiplexed with the azimuthal or vertical guidance signal (reference 121). Another scheme is time-sharing so that a scanning slot (of time) is open and the scanning antenna is used exclusively for DME functions. Another method is to use a separate antenna so that the exact timing for the direct path on the high gain beam is avoided. This reduces path gains (to and from the aircraft) considerably and may require greater power, or a restriction on the azimuthal coverage of the DME. DME has its greatest penalty in the aircraft where a separate transmitter is needed. The passive DME concept of a range-gated radar return (only at short ranges) is cheap and could be a simple small module of importance to V/STOL operations. This concept assumes only one aircraft in the range gates and the reflected guidance signal (which is also received in the air) is examined to determine the exact location of the airport in range only for the last mile or so. This ground signal is then relayed to the aircraft utilizing the same proportional coding of the angular system, thus employing the already available airborne receiver and decoder. This signal can be stored for an interlaced scan period. The airborne equipment is then fully passive (sometimes an important military consideration) and a means of assuring the use of the range signal to the single aircraft is needed (height may be adequate).

Another intriguing and widely variable equipment is the SSR (or IFF beacon--"AIMS" transponder) operating in L-band. By cross-banding (using the microwave guidance for interrogation) of the AIMS transponder and employing the airborne reply much as any DME (on the ground), the aircraft can achieve a three-way transmission loop. Both air and ground can have range indication in this manner. In fact, a cheap, high-performance "secondary GCA" exists with these signals.

For those aircraft that have TACAN, the TACAN-DME can also be used, but has the standard disadvantage of a wide, shaped pulse, with poor leading edges. The sharp rise of the SSR (AIMS) pulses have a more inviting characteristic if reasonable DME accuracy for landing is desired. The AIMS pulses are measured in tenths of microseconds while the TACAN-DME is measured in full microseconds. About an order of accuracy advantage of AIMS/DME over TACAN/DME should exist, though means for improving TACAN/DME are under test and study at present (references 18 and 19).

The DME function, not always being needed, is considered optional in many applications and its multi-choice modular addition when needed is desirable. It may be added to either vertical or horizontal guidance sites or used separately for other functions such as R-θ coverage.

Table V is a summary of "Rules of Thumb" for fixed-beam guidance techniques and ground-scanning beams.

TABLE V

SUMMARY OF RULES OF THUMB FOR
FIXED-BEAM GUIDANCE TECHNIQUES
AND GROUND SCANNING BEAMS

FIXED-BEAM GUIDANCE TECHNIQUES

1. For good vertical guidance, less than -6 db should illuminate the ground to avoid reflections that create nonlinear meter action, flat spots, reversals, etc.
2. Beamwidths (3 db) should be slightly less than the lowest desired glide path.
3. Multiple false courses due to side lobes are possible, starting about $1\frac{1}{2}$ beamwidths off-course.
4. Limit high-angle applications because of 3 above to avoid false courses below the path.
5. Course width limited to about $\frac{1}{2}$ beamwidth (a wider width has a low db/degree change forcing the lower lobes onto the ground).
6. Course width is variable--about 40 percent.
7. Wide azimuthal beams illuminating objects create course bends, narrow beams have some lobe suppression problems, and again db/degree is important to course quality and stability.

GROUND SCANNING BEAMS

1. Side-lobe suppression requires AGC over two to three scan periods.
2. The lowest proportional guidance angle is based on beamwidth (about $\frac{2}{3}$ a beamwidth).
3. Radiating while vertical beam is pointed at negative angles creates false courses.
4. Linear beam (proportional region) is about the scan angle minus $2 \times$ the beamwidth.
5. A clearance signal beyond the scan angle is needed for certain applications in horizontal guidance.
6. Course width cannot exceed scan angle below (or above) the selected course in vertical guidance applications.
7. Course sensitivity above a vertical path can be different than below.
8. Some forms of static beam transmissions can be made to appear in a scanning beam receiver as a scanning beam signal over a limited angle.

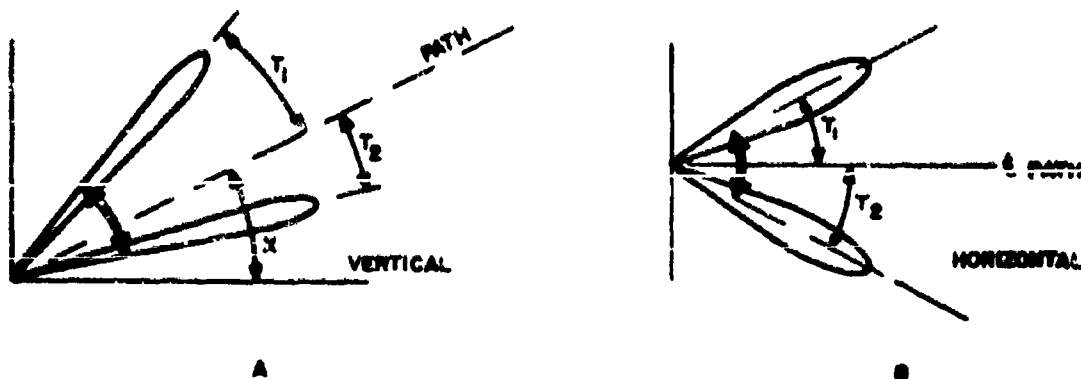


FIGURE 45. SIMPLIFIED SCANNING BEAM ENCODING

j. Simplified Scanning Beam Encoding

Where large angular coverage is desired, some accuracy degradation is acceptable, and simplicity of airborne units is of highest priority; for this purpose a simple airborne decoder can be used. Take the vertical example (Figure 45A) where the beam scans some fixed vertical angle at some constant scanning rate. The fixed vertical angle and constant scanning rate are both easily obtained characteristics for scanning beams (1 part in a 1000 for each). As the beam scans in a reciprocating motion (up scan and down scan), it will be noted that the path (dotted line) is defined by comparing T_1 with T_2 . The beam direction is determined by simply switching a constant modulation signal (constant tone or PFR) so that the up scan is one constant modulation and the down scan is another.

An inexpensive airborne timing (10^5) reference (tuning forks, crystal, or clock) measures the difference between the reception of the nose of the beam (beam splitting is a common art). Thus, intervals T_1 and T_2 are equal if the path is midway in the scan angle. Say the total angle (x) is 20 degrees: at 10 degrees one would find the two periods between up and down scans equal. At 5 degrees the period would be such that $T_1 = 3T_2$ (5 degrees = 3×5 degrees). The airborne receiver now takes on the nature of a simple unit that is a detector with two filters (one for up and one for down scans) and a timing circuit. Compared with the encoding of the various scanning beams that have been built (i.e., REGAL, etc.), this would simplify certain airborne units considerably (Figure 46).

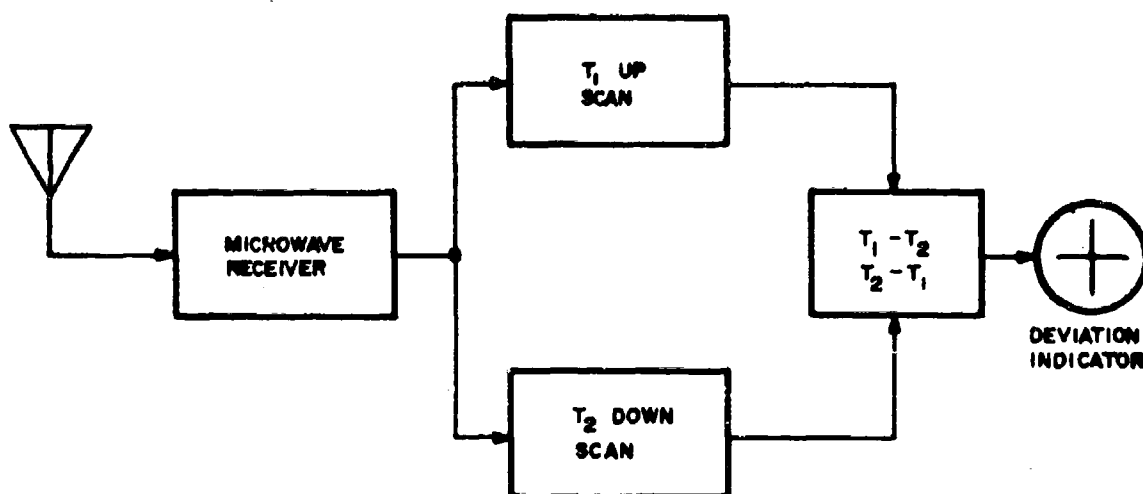


FIGURE 46. SIMPLIFIED SCANNING BEAM DECODING

The extent of modularity should be determined in more detail, but an illustrative breakdown might be helpful at this point.

<u>I</u> <u>Primary Electrical</u> <u>Power</u>	<u>II</u> <u>Ground Beam</u> <u>Transmitter</u>	<u>III</u> <u>Modulation</u>
a. Battery	a. Low power	a. Vertical guidance
b. Gas cells	b. Medium power	b. Horizontal guidance
c. Gasoline generators	c. High power	c. DME
d. Turbine	d. Low duty cycle	d. Simplified timing
e. Base power	e. High duty cycle	e. Other analog
<u>IV</u> <u>Ground guidance</u> <u>Antennas</u>	<u>V</u> <u>Ground DME</u> <u>Functions</u>	
a. Small fixed	a. Microwave receiver	
b. Medium fixed beam	b. SSR-AIMS Receiver	
c. Small-scanning	c. Radar-range gate	
d. Large-scanning	d. All utilize I - IV	

For example, modular system I might use sub-elements Ia, IIa, IIIb, IVb and Vb; as another example, modular system VI might use Id, IIb, IIIabc, IVd and Va.

These basic elements can be packaged into various landing guidance systems configurations to meet varied tactical requirements. In order to minimize the number of elements further study is obviously warranted.

k. Permutations of Modules 1 through 8

It should be noted that there are permutations of various basic modules that were previously described. For

example, Module 1 could use a narrow fixed beam overlapped with a wider upper beam to minimize lobes causing false courses above the intended course. "Tapered" radiation patterns may help to reduce the proximity of the false courses created by side lobes. Except for making the radiated signal directive, no techniques seem suitable for reducing ground reflections in the vertical plane that cause adverse glide path deviation indications (flat spots, non-linearity, reversals, lack of full scale deflection). This means that there should be a beam slope near the horizon of about 6 to 10 db/degree for steep angles. The section on Fundamentals of Landing Guidance describes this limitation in more detail.

Another possibility is a multiplicity of beams, each overlapping the adjacent one 3 to 6 db down from the beam nose. For example, five beams each 2 degrees wide overlapped at the 3-db points would cover about a 10-degree sector, providing a number of discrete paths. The beam-switching and modulation, however, can become complex and, to assure the same coverage, the antenna must be nearly coincident. An electronic means such as a "Wullenweber" static scanner may be possible, but such an antenna has not been tested for the demanding beam requirements of instrument landing guidance.

Again, it should be noted that Modules 1 through 8 are described to illustrate the basic methodology for arriving at a building block-modular, multi-function tactical landing system design.

8. STEP VII--OPERATION SYSTEMS CONFIGURATIONS

The modular design concepts described in the previous section are intended to be utilized to configure different overall Tactical Landing Systems. The criteria for specific configurations include the following:

1. Desired ceiling limits
2. Aircraft characteristics (aerodynamics, maneuverability, size)
3. Size of landing strip (length, obstacle clearance)
4. Other landing aids (runway lights, TACAN, VASI, arresting gear, electrical power), etc.
5. Desired portability (or air lift transportability)

6. Economics

7. Safety

For any particular mission any one of these can have an overriding influence. For example, the risks in IFR landing in a battle zone are high, but the accidents should be kept low. To maintain adequate safety standards ceilings are usually prescribed for each configuration or landing aid. For typical civil examples, the ICAO has done this; however, a similar set of tactical criteria must also be developed. Accident investigations will determine the allowable losses due to poor IFR landing capability. A landing system improperly engineered, installed, or utilized can be lethal. The Air Force is as diligent in accident analysis (tactical or otherwise) as the CAB. Any over-extension of a particular module or electronic aids for IFR will show up in landing accident statistics. Even in civil operations, where one expects more controlled conditions, landing accidents account for half the fatalities of the airlines. It is consequently a sensitive area that, if not solved correctly, can inhibit the IFR utilization of tactical aviation.

Other considerations may be simple ones, such as the problem of physically installing the units. This is one reason ICAO-IIS should not be considered--since extensive site preparation, equipment adjustment, and flight inspection, often taking weeks, is needed. Furthermore, the modern 100-foot antenna structures for localizers and glide paths (needed for poor sites) are enormous in size and weight (relative to a microwave system).

An air drop mission may utilize only a small azimuthal guidance unit so that the pilot can align the aircraft. Perhaps he is partially lost; and even to locate the general area of the drop point, this unit is needed. Since visual sighting is quite unreliable in unprepared and unmarked areas, even the target point may not be visible until too late. Thus, the small azimuth unit would be man-packed and battery-powered. The 2-foot dimensional limits and packages (maybe two) not weighing more than a man can carry on his back should be considered. In current and future brush warfare, the dependence on the airplane and helicopter is reaching the point that it may be as essential to have such an electronic unit for survival (via airdrop) as it is to carry a gun or a mortar.

In other words, the tactics, both in the Air Force and particularly the Army, are changing to such an extent that greatly improved means for quickly and accurately locating drop and landing sites are essential to the success of modern military concepts. The truck, mule, and rail support concepts of World

Wars I and II seem to have been extensively replaced by air support for supplies, fire power, personnel movements, and increased fluidity of battle (front lines hardly exist).

Combinations of various modules will be illustrated in Figures 47 through 50. It will be noted that, though the same two units may be used in certain cases the separate siting of the vertical and horizontal guidance modules achieves certain important operational advantages. This is particularly true in cases where the vertical guidance is located ahead of the landing threshold (land-flares). Other reasons include cases in which the vertical guidance is located within the clearance (inside threshold), and steep angles are used to achieve a suitable obstacle clearance line. Narrow and sharp beams can be mixed as well as the use of angle and DME to compute forward paths (Phantom glide paths). Bi-angular glide paths (reference 52) can also be readily achieved in several ways. Criteria for vertical and horizontal guidance differ sufficiently that co-location may be a serious limitation.

It is not intended here to recommend the final configurations, and in fact they may well be less than those enumerated. It is the intention, however, to relate the modular elements to potential Tactical Landing System configurations. It is also possible to evolve into such a concept without building all possible units or combinations. However, the growth potential for some 20 years must be considered as it is likely that it will not be possible to replace such a major system determination for such a period. TACAN, ILS and VOR are examples. Furthermore, the ICAO-ILS will continue to serve for a decade or more and many Air Force aircraft will continue to carry two landing systems (ICAO-ILS and Tactical Landing). It is evident that the ability to optimize each site is essential to flexibility in choice of landing strips. Co-location of modules is not prevented and additional savings in equipments can also be achieved.

a. Airborne Elements (Figure 51)

As noted previously, the numerous steps leading up to the "Signals-in-Space" standard of frequency, beams, modulation, physical size, etc., have each had an effect on the airborne equipments. Although the airborne units must be the most common, there is little to bias the standards from the airborne equipment side. The technology for airborne implementation of the two most likely microwave frequencies is nearly comparable.

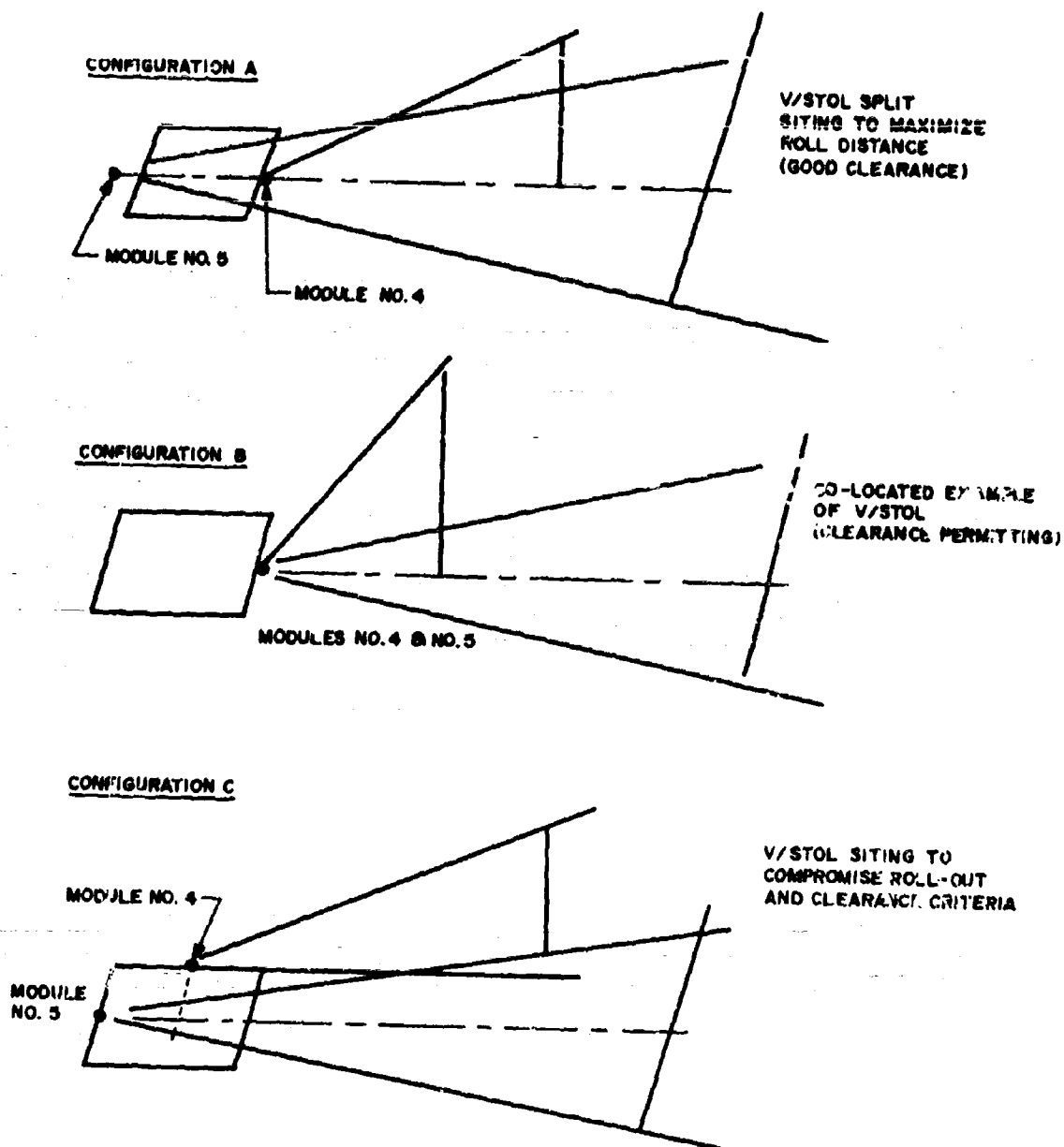
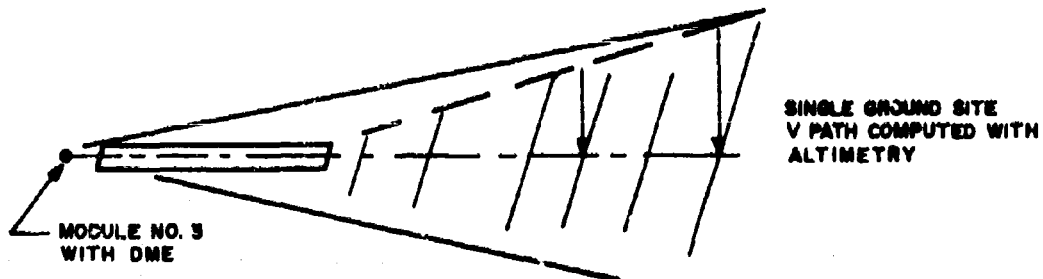
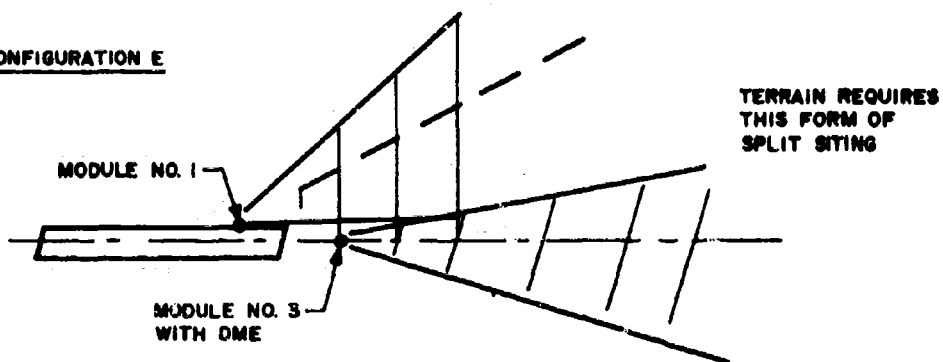


FIGURE 47. VARIATION IN SITING OF SPECIFIC MODULES
(Configurations A through C)

CONFIGURATION D



CONFIGURATION E



CONFIGURATION F

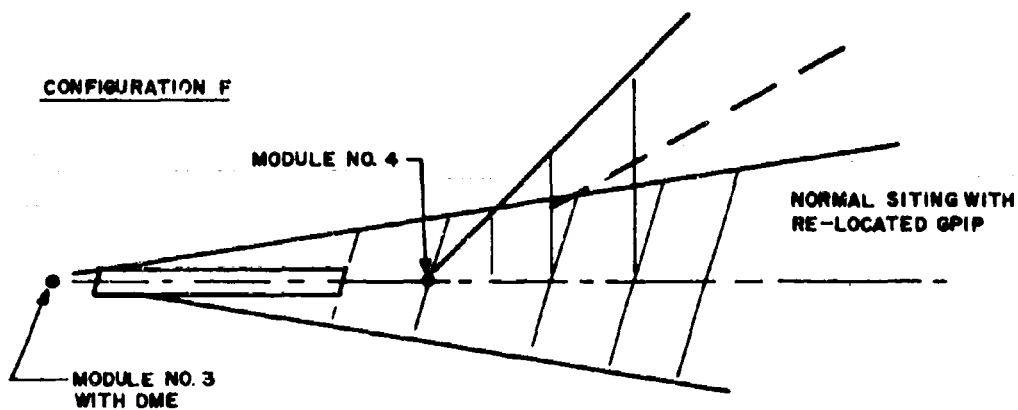


FIGURE 48. VARIATION IN SITING OF SPECIFIC MODULES
(Configurations D through F)

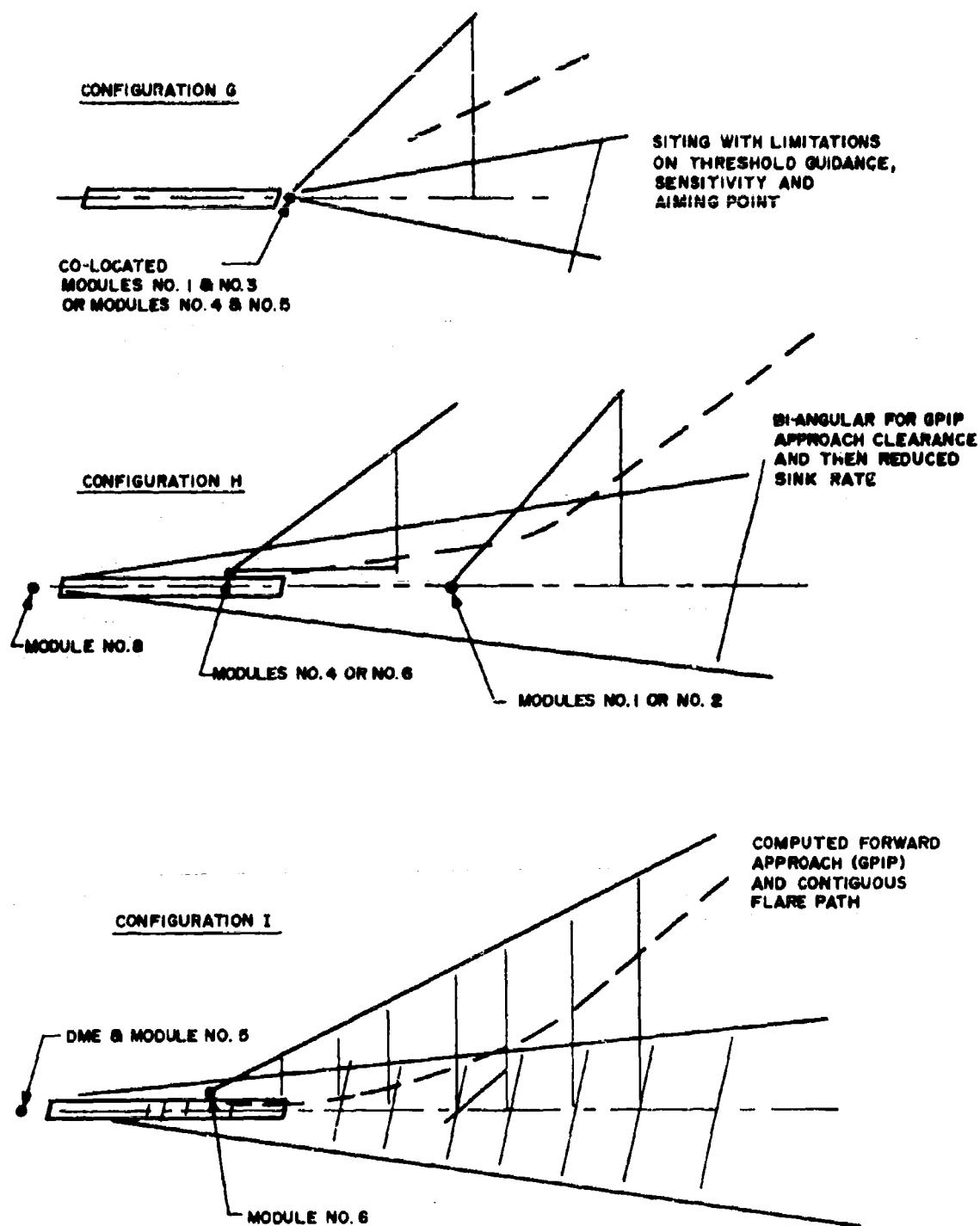


FIGURE 49. VARIATION IN SITING OF SPECIFIC MODULES
(Configurations G through I)

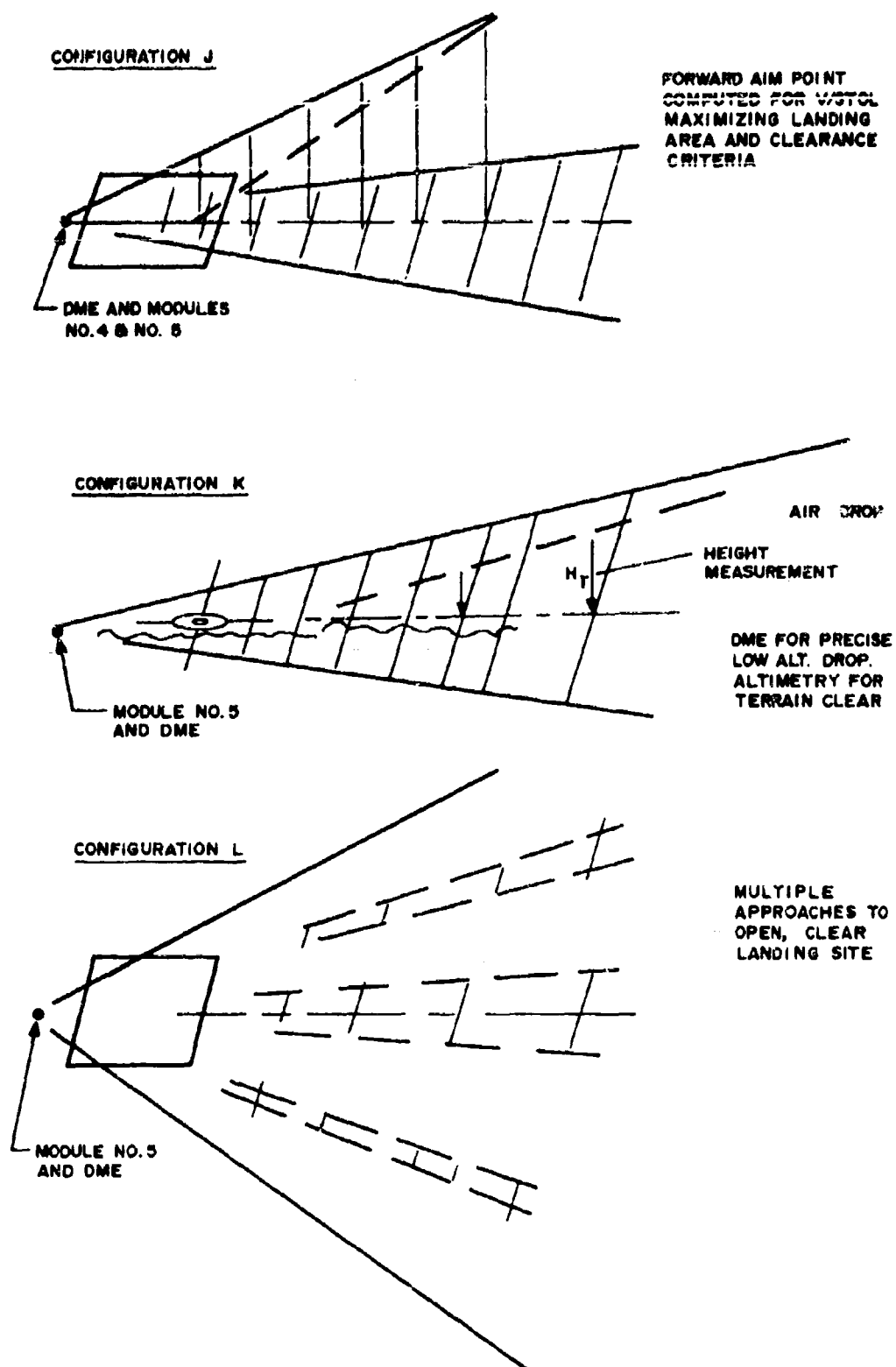


FIGURE 50. VARIATION IN SITING OF SPECIFIC MODULES
(Configurations J through L)

It is important that the ground module choices assure the maximum usage of common airborne receiving equipment. There may be some areas where specialized airborne units can still conform to the standards, but do not find service with the large variety of ground configurations just noted.

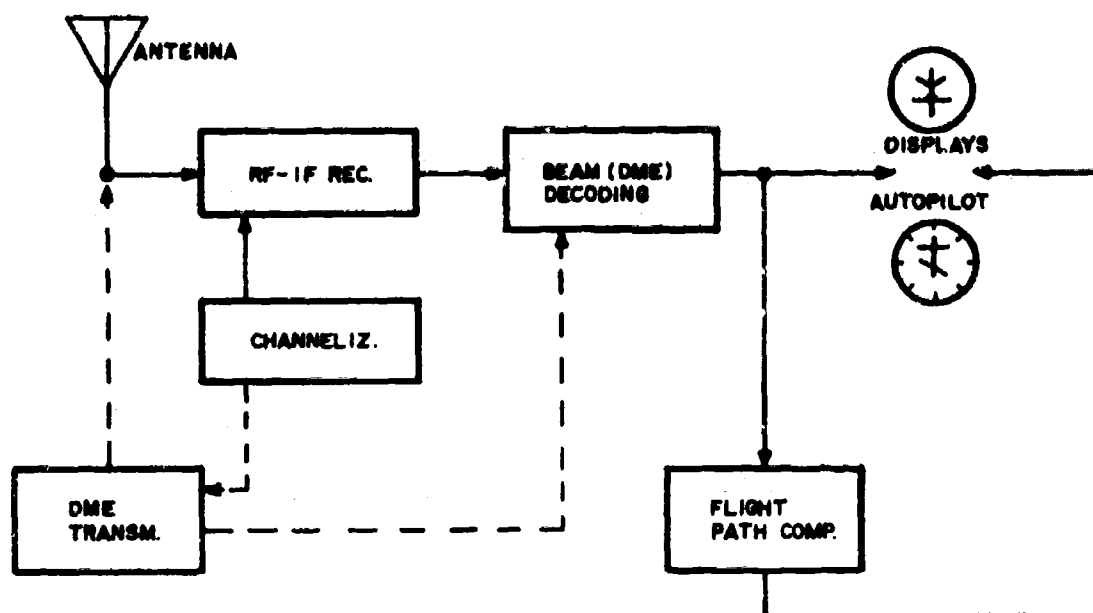
Aircraft, such as carrier aircraft, that fly without flare into arresting cables, might be an example. Although the ship equipment can be specialized, there is little likelihood of a large airlift aircraft utilizing this system. However, a helicopter may well want to use the system when going from the ship to shore for transport of supplies or personnel. The basic modules of the airborne equipments can be varied within limits. For example, the channelization may be limited to certain channels in some equipments and fully channelized in others, depending on the mission. The most costly elements in the airborne equipments will be the channelization devices, receiver, and decoding equipments. The cost of the addition of DME can be kept to a minimum if it uses these same elements. The additional cost is then little more than the airborne transmitter (tube and modulator).

In order to obtain the flexibility of path angle (that appears essential for a tactical system) a decoding scheme with a wide range of precisely selectable paths will be necessary for several applications (Configurations A, B, C, I, J, and L). This unit is also likely to be suitable for the limited cases of single paths at fixed angles. The ground units all would utilize the same beam coding at specific angles so that the airborne decoder will process all signals on a basic time multiplex, or pulse multiplex basis. This feature is one airborne requirement that must necessarily be met by the standards; or separate receivers for the separate signals, glide path, localizer and DME will prevail.

It is possible to employ the airborne equipments without a flight path computer so it could be an additional, optional unit that is employed when needed. There is, also, the possibility of a simplified (timing of beam passages) receiver that would minimize the decoding requirements considerably.

b. Time Phasing of development steps

It is not essential to complete each step suggested before starting the next one. Some of the steps leading up to the choice of radio frequency may be overlapped. Some preliminary equipments to aid in the frequency decision may be necessary.



Each module can have variations, but conforms to Standards for Signals-in-Space of ground units. DME is optional, but preferably utilizes as much of airborne complement as possible.

FIGURE 51. BASIC MODULES FOR AIRBORNE EQUIPMENTS

The important point is that the interrelationships of the first 5 steps must always be borne in mind. After Step V the major project decisions are based on the modular designs. The examples herein given are for examples only, since the thorough synthesis provided in the previous steps will be far more inclusive than this brief study of the problem.

The point of no return starts to be reached at Step VI, since the costs of the designs and fabrication of them will start to mount.

Figure 52 illustrates one possible time phasing of the various elements. Before and after the key decision--the choice of radio frequency--parallel efforts may be taken to shorten the overall time. It is probable that once a tactical landing system does start to evolve the gross procurements will be similar to the TACAN program so that it is essential that a thorough job be done in Steps I through VII.

9. STEPS VIII AND IX--SOLUTIONS TO TACTICAL LANDING NEEDS AND INTERFACES WITH OTHER USERS

Steps VIII and IX are natural outgrowths of all the previous steps and are therefore not discussed here as separate items.

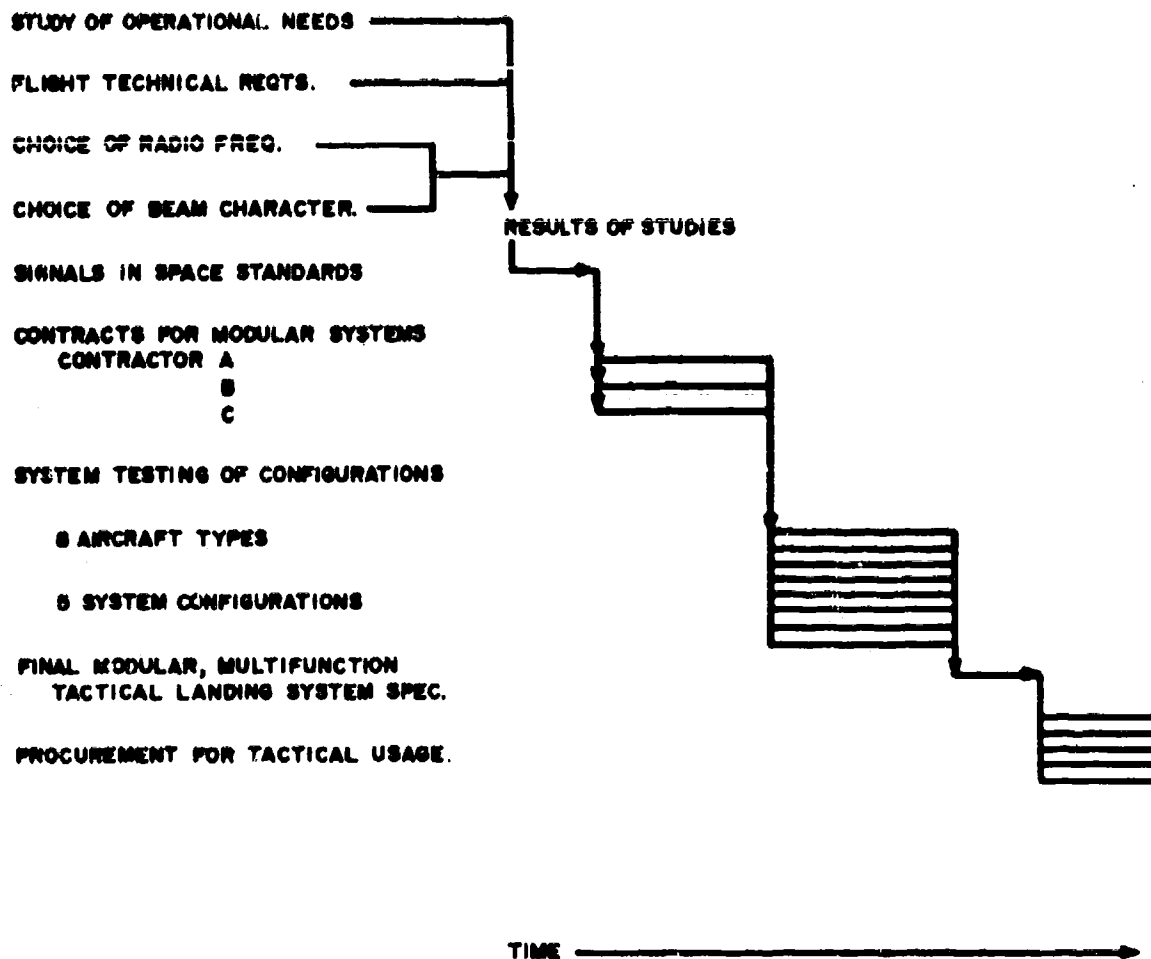


FIGURE 52. TIME PHASING OF TACTICAL LANDING SYSTEM

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

Recommendations and conclusions often accompany the different subject matter as it is discussed in the report. This has the advantage of justifying the reasons for such recommendations or conclusions without having to search through the report.

The following are considered the most significant conclusions and recommendations, but are not representative of all the detailed ones that will be found by reading the text.

CONCLUSIONS

1. Many Air Force missions, such as the multi-billion dollar investment now being made to increase airlift capacity by an order of magnitude, are heavily dependent on a complementary tactical landing system.
2. The current ICAO/FAA-ILS/GCA program will not meet the needs of a flexible tactical landing system.
3. The wide variations in Air Force missions and aircraft types require a new multi-functional tactical landing system program that is flexible for rapid siting and operational utilization without sacrificing reliability or safety. Microwave techniques appear the most promising.
4. Self-contained systems are inadequate for ILS type landing guidance because they do not have the required accuracies. They may, however, serve as terminal aids for intercepting the coverage diagram of a portable microwave landing system.
5. The current proliferation of tactical landing system developments is creating confusion and is wasteful of government and industry efforts, since most of them are incompatible and are not likely to meet realistic tactical needs.
6. The Air Force will have two landing systems for some time: Standard ICAO-ILS and a new tactical landing system. A third or fourth incompatible system should definitely be avoided.

7. Testing of tactically suited techniques for relocating the GPIIP is urgently required. The high risk and record of accidents associated with "duck-under" indicate that a 300-foot ceiling is a realistically safe visual contact height with current high-performance jet aircraft. A relocated GPIIP could greatly improve this situation.
8. The FAA-airline plans to use radio altimeters for continuation of guidance beyond heights of 100 to 200 feet will not be feasible in typical tactical environments or with high-performance jet aircraft at improved environments.
9. A new modular multi-functional, tactical landing system suitable for applications ranging from minimum, portable, bare base installation to a total system suitable for the most demanding aircraft requiring precision touchdown, long flare-out trajectories, etc., is feasible with today's technology.
10. Typical visual lighting aids (3000 feet of approach lights), essential for the "see-to-land" concepts of CAT I, II, and III, will not be available at most tactical fields, placing increased emphasis on the quality, reliability, and safety of the tactical radio guidance system.
11. No integrated standards or guide lines exist for tactical landing development, procurements, deployments, flight inspection or selection of sites. These must be developed as fully as the civil (counterpart) standards typified by ICAO documentation.
12. A "Signals-in-Space" standard must be developed within the Air Force or even within DOD, and is essential for guidance in selection of tactical landing systems.
13. An organized effort, commensurate with the total problems does not now exist in the Air Force.

RECOMMENDATIONS

1. A project approach is needed rather than the current piecemeal approach to the overall program for developing a multifunctional, tactical landing system.
2. Emphasis should be placed on cooperative techniques rather than on self-contained or radar techniques.
3. Develop as soon as possible a multifunctional tactical landing system "Signals-in-Space" standard.

4. Industry and government effort should be directed toward a modular system standard to provide the maximum commonality of aircraft equipments and to reduce the current proliferation of diverse tactical landing systems to a minimum.
5. A photo-measurement program should be initiated for determining the landing profiles of the many varied types of Air Force aircraft. This is urgently needed as a design input to determine Guidance System Parameters such as beamwidths, siting, aim points, flare guidance and the extent modular design should be carried.
6. Techniques suitable for eliminating the duck-under maneuver without increasing the landing risk should be tested using the same type aircraft. The results should be incorporated in the tactical design parameters.
7. A technical staff should be developed that is capable of dealing with the total landing problems. The technical "know-how" needed for guidance decisions (frequencies, beamwidths, lobing techniques, etc.), must be as fully developed as the instrumentation and control "know-how."
8. Sufficient facilities should be established for testing the guidance program techniques and equipments with the actual aircraft they are to serve. Supporting elements of air and ground flight test measurements with appropriate rapid data processing will also be essential to success in the tactical landing area.
9. Tests should be conducted under full black-out conditions with radio guidance that is sufficiently self-assured and reliable that no-light (night) landings can be made. Tactical landing environments will not be suited to the extensive approach and runway lighting systems now used.
10. A set of operational standards should be proposed for tactical landing strips describing clearance, length, width, gradient, touchdown points, etc., for tactical aircraft, so they can be classified for appropriate modules of the tactical landing system.
11. The continuation of a cooperative effort with other services should provide valuable inputs and minimize Tri-Service incompatibilities as the Air Force Tactical Landing System develops.

SECTION IX

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APPENDIX
A STUDY OF GCA TOUCHDOWN POINTS

FLIGHT TEST REPORT FLIGHT AND ENGINEERING TEST GROUP		E. GWS NR 60-38 <input type="checkbox"/> DRAFT <input checked="" type="checkbox"/> FINAL	
		1. DATE 31 August 1960	
2. TEST TITLE A Study of GCA Touchdown Point		4. PROJECT OR TASK NR 913A(61)	
3. GWS FORM NO IDENT NR WOTE 60-3A		5. PRIORITY 1A	
6. OBJECTIVE AND SUMMARY			
OBJECTIVE			
1. Flight tests were conducted to determine the distance between GCA touchdown point and actual touchdown point for century series fighter-type aircraft when making an instrument approach to GCA minimums.			
SUMMARY			
2. The distance from GCA touchdown and actual touchdown for century series fighter aircraft (F-100, F-101, F-102, F-104, and F-106) was determined from flight test results. The results showed that the <u>distance between GCA touchdown point and actual touchdown point</u> may be as much as <u>2,400 feet</u> during normal operations.			
CONCLUSIONS			
3. It is concluded that the <u>runway length</u> remaining beyond GCA touchdown point is effectively reduced by as much as <u>2,400 feet</u> when landing is accomplished from an instrument approach to GCA minimums.			
(Continue on separate sheet)			
7. FLIGHT HOURS COMPLETED Sixty-Two Flights		FLIGHT HOURS REMAINING None	
8. REQUESTING AGENCY All-Weather Flight Test Branch		11. AIRCRAFT IDENTIFICATION F-100, F-101, F-102, F-104, and F-106	
9. TEST STARTING DATE 1 March 1960		12. TEST LOCATION (S) W-PAFB	
10. TECHNICAL (Report) (Note) TO BE ISSUED N/A		13. FLIGHT TEST PILOT Capt J. C. Herdway	
14. FLIGHT TEST ENGINEER		15. REQUESTING AGENCY RESPONSIBLE AGENT Major Roy R. Croy, Jr.	
16. PREPARED BY Mr. I. D. Harris <i>I. D. Harris</i>		17. <i>Webster W. Plourd</i> WEBSTER W. PLOURD, Lt Colonel, USAF	
18. TECHNICAL DIRECTOR CONCURRENCE <i>Joseph Davis, Jr.</i> JOSEPH DAVIS, JR, Colonel, USAF		19. ENCLOSURES <input type="checkbox"/> APPS <input checked="" type="checkbox"/> TABLES <input type="checkbox"/> FIGURES	
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RECOMMENDATIONS

4. It is recommended that the results from these tests, i.e., the average distance from GCA touchdown point to actual touchdown point for each fighter-type aircraft be included in Section IX of the applicable Flight Manual.

TEST AIRCRAFT

5. Standard F-100, F-101, F-102, F-104, and F-106 aircraft were utilized for the test. The F-105 aircraft was not available during the test period.

6. The aircraft were operated in the standard configuration. Gross weights and center of gravity location were those normally encountered during instrument approach conditions.

TEST PROCEDURES

7. The majority of pilots probably accept at face value the runway length which is found in publications, sometimes overlooking the fact that the effective length may be reduced during a low ceiling GCA because of the following factors:

- a. Location of GCA touchdown point
 - b. Breakout altitude and technique used in the flare and landing
 - c. Power used in flare and landing
 - d. The GCA touchdown point may represent a point where a fighter-type aircraft is still twelve (12) feet in the air because it is predicated on the height of the radar blip, which will also accommodate a C-124 without guiding the C-124 into the ground; therefore, extra runway is used to ease a fighter-type aircraft down from this 12-foot height.
 - e. Higher airspeeds may be required to effect a flare at a certain glide slope angle and in turn require more runway.
8. The tests were performed as follows:
- a. A normal take-off and climb to low approach altitude was made.

b. A request for entry into GCA pattern was made when normal landing weight was attained.

c. Recommended instrument approach airspeed and configuration were used to complete the GCA pattern.

d. GCA controlled glide path and heading were maintained to GCA minimums (100 ft), and the pilot then landed on the runway centerline using VFR procedures.

e. The pilot recorded glide path airspeed, power setting, touchdown airspeed, and fuel remaining.

f. The aircraft was tracked and photographed with photo-grid camera from a point on GCA glide path prior to established GCA minimums (100 ft) to touchdown point.

TEST RESULTS AND DISCUSSION

9. Landings were made from GCA by sixteen test pilots during forty-two flights using the 2-1/2° and 3° glide slope. The pilots were alternated between the various type aircraft used and the results reflect a cross-section of varying pilot technique in flare-out and landing.

10. The number of flights and type of aircraft were as follows:

	F-100	F-101	F-102	F-104	F-106
3°GS	3	3	3	4	5
2-1/2°GS	6	3	5	5	5

11. Results were corrected to a zero wind condition and the average distance between GCA touchdown point and actual touchdown point are shown in the following table:

	F-100	F-101	F-102	F-104	F-106
3°GS	2,000 ft	1,700 ft	1,700 ft	2,100 ft	1,900 ft
2-1/2°GS	2,400 ft	1,800 ft	1,800 ft	2,200 ft	2,000 ft

DISTANCE FROM GCA TOUCHDOWN
TO ACTUAL TOUCHDOWN (CORRECTED)

	3°0.8.	2-1/2°0.8.
F-100	1427 Ft	2130 Ft
	2550	2725
	1900	2603
		2693
		2384
		1894
F-101	1550	1750
	1515	2051
	1976	1477
F-102	1375	1851
	1635	1755
		2000
		1601
	2031	1757
F-104	2089	1736
	2015	2485
	2101	2430
	2283	2220
		2077
F-106	1789	1725
	2046	2159
	1980	1933
	1852	1450
	1595	2500

DOCUMENT CONTROL DATA R&D		
1. REPORTING OFFICE 32 Cherry Lane Northport, N. Y. 11768		2. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 3. GROUP N/A
4. REPORT TITLE SYNTHESIS OF A MULTIFUNCTIONAL TACTICAL LANDING SYSTEM		
5. DESCRIPTIVE NOTES (Type of report and inclusive dates) None		
6. AUTHOR(S) (Last name, first name, initial) George B. Litchford		
7. REPORT DATE January 1967	7a. TOTAL NO. OF PAGES 189	7b. NO. OF REFS 124
8a. CONTRACT OR GRANT NO. AF 33(615)-3199 b. PROJECT NO 682C c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) None 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFFDL-TR-67-188	
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13. ABSTRACT This report is an attempt to outline the methodology and means required to establish the characteristics for a low visibility tactical landing system. Low visibility landing, and particularly the restraints placed on a tactically acceptable system, are probably the most demanding of any of the current technological problems facing the Air Force. As experience indicates, there are no short-cuts to success in this field. First, a logical step-by-step process for synthesizing a tactical landing system program is essential. With adequate interest personnel, facilities, and funding, a suitable solution can be developed. The magnitude of the effort, and the often unsuspected inter-governmental impact of tactically justified development of navigation facilities are outlined. Those not familiar with these somewhat non-technical aspects of the problem should carefully consider their significance. The challenge is to establish a program that will lead to the adoption of an electronic "Signals-in-Space" standard. This, in turn, will permit various forms of the basic system to evolve while maintaining airborne commonality with as many ground services as possible.		

DD FORM 1473
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Just as an aeronautical engineer designs a successful aircraft by use of recognized ground rules or by consideration of wings, engines, mission, etc., so must the designer of tactical landing systems learn to consider radio frequencies, beams, modulation techniques, etc.

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